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Human Factors Evaluation of Existing Side Collision Avoidance System Driver Interfaces

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ABSTRACT

This paper describes the assessment of driver interfaces of a type of electronics-based collision avoidance systems that has been recently developed to assist drivers of vehicles in avoiding certain types of collisions. The electronics-based crash avoidance systems studied were those which *detect* the presence of objects located on the *left and/or right sides* of the vehicle, called Side Collision Avoidance Systems, or SCAS.

As many SCAS as could be obtained, including several pre-production prototypes, were acquired and tested. The testing focused on measuring sensor performance and assessing the qualities of the driver interfaces. This paper presents only the results of the driver interface assessments. The sensor performance data are presented in the NHTSA report "Development of Performance Specifications for Collision Avoidance Systems for Lane Changing, Merging, and Backing -- Task 3 - Test of Existing Hardware Systems" [1].

One goal of this research was to evaluate, based upon the principles of human factors, how well the driver interfaces of the SCAS studied were designed. The strengths and weaknesses of each driver interface were determined. Overall, while none of the SCAS had an "ideal" interface, most had ergonomically acceptable interfaces. Not surprisingly, the commercially available systems tended to have better driver interfaces than did the prototypes. Another goal of this research was to provide advice to future designers of collision avoidance system driver interfaces regarding ergonomically desirable or undesirable features. From the evaluations performed, a preliminary set of driver interface performance specifications that may be of aid to future SCAS driver interface designers has been developed.

INTRODUCTION

This paper describes the evaluation of driver interfaces of a type of electronics-based system that has been recently developed to assist drivers of both light (passenger cars, pickup trucks, vans, and sport utility vehicles) and heavy (straight trucks and tractor-semitrailers) vehicles in avoiding certain types of crashes. The driver interface is defined as the displays and controls through which the driver interacts with the CAS and receives collision avoidance warning information. The type of electronics-based Collision Avoidance Systems, or CAS, examined was that which *detects* the presence of objects located on the *left and/or right sides* of the vehicle (referred to as side-looking collision avoidance systems or SCAS). These side-looking systems are intended primarily as supplements to the existing side- and rear-view mirror systems. The SCAS assist the driver during lane changes and merges by detecting adjacent vehicles.

This research was performed as part of a larger research program, "Development of Performance Specifications for Systems Which Assist in Avoiding Collisions During Lane Changes, Merging, and Backing" sponsored by the National Highway Traffic Safety Administration (NHTSA). The research was performed by TRW's Space and Electronics Group with assistance, during the Phase 1 testing, from NHTSA's Vehicle Research and Test Center (VRTC) and various subcontractors.

A portion of Phase 1 (Laying the Foundation) of the research program "Development of Performance Specifications for Systems Which Assist in Avoiding Collisions During Lane Changes, Merging, and Backing" was devoted to examining existing collision avoidance systems. As many SCAS as could be obtained, including several pre-production prototypes, were acquired and tested by TRW and VRTC. The focus of testing was on measuring the performance of the SCAS sensors and assessing the qualities of their driver interfaces. This paper documents the results of the evaluation of driver interfaces. A companion report, "Development of Performance Specifications for Collision Avoidance Systems for Lane Changing, Merging, and Backing -- Task 3 - Test of Existing Hardware Systems" [1], documents the examination of the SCAS sensors and the results of the assessment of their performance.

This paper is a summary of the NHTSA technical report "A Human Factors Assessment of the Driver Interfaces of Existing Collision Avoidance Systems" [2]. Readers desiring additional details about this research should consult this reference.

PURPOSE

The goals of this research to evaluate the design of existing SCAS driver interfaces were:

1. To evaluate, based upon human factors principles, how well the driver interfaces of the SCAS studied were designed. This included examining such issues as the effectiveness of the interface designs in conveying information to the driver, considering the effect interface designs might have on overall driver workload, and determining whether or not the interface designs would unduly distract or annoy drivers.

2. To provide preliminary advice to designers of SCAS driver interfaces regarding potentially desirable or undesirable features and qualities of the interfaces as based upon the principles of human factors. The intent of this goal is to promote better driver interface designs by allowing designers to easily understand the strengths and weaknesses of current designs.

3. To identify SCAS driver interface design issues that should be the focus of future research. While existing human factors literature provides recommendations about many aspects of man-machine interface design, several aspects important to SCAS for automobiles and trucks are not addressed in the literature. Identification of important design issues will encourage future researchers to develop the needed guidance.

4. To improve methods for evaluating SCAS driver interface designs. The development of better, standardized methods for evaluating driver interface designs for collision avoidance systems will both improve the quality of research on this topic and allow engineers to evaluate their own designs, resulting in more user-friendly products.

SYSTEMS EXAMINED

For this research, the driver interfaces of seven SCAS were studied. Of these systems, two were commercially available and five were pre-production prototypes. The two commercially available systems constituted all of the commercially available SCAS known to NHTSA at the time of initiation of the study. The five pre-production prototypes were all of the prototype SCAS known to NHTSA at that time.

While the focus of this research addressed the use of SCAS for light vehicle applications (passenger cars, pickup trucks, vans, and sport utility vehicles, all with gross vehicle weight ratings below 44,500 Newtons) several of the systems evaluated were intended primarily for use on heavy trucks. The heavy truck systems were included in this study because:

1. There are no major functional differences between the operation of heavy truck and light vehicle SCAS. Heavy truck and light vehicle CAS differ primarily in the size and shape of the zones around the vehicle in which driver's awareness of traffic, pedestrians, and other obstacles needs to be improved. However, the fundamental functions of the SCAS, detecting objects around the vehicle (or enhancing driver vision) and conveying information to the driver are the same for both heavy and light vehicles.

2. Examining many systems allowed for a better understanding of the available and desirable capabilities and qualities of SCAS. Examining multiple systems maximizes the range of system capabilities seen and makes it less likely that an important capability may be overlooked. In this study, although all available SCAS intended for use in both heavy and light vehicles were examined, there still were not very many systems of each type examined.

The objective of this research was to report findings related to the CAS driver interface. However, due to the methodology used in this study the performance of a system's driver interface was, to some extent, intertwined with the performance of that system's sensors. This study examined SCAS as whole units. No attempt was made to disassociate a system's driver interface from a system's sensors (as could be done by, for example, connecting a driver interface to an "ideal" sensor). Therefore, to allow readers to better understand each SCAS, a brief summary of the most important characteristics of each system's sensor performance is included below. This material was taken from the "Development of Performance Specifications for Collision Avoidance Systems for Lane Changing, Merging, and Backing -- Task 3 - Test of Existing Hardware Systems" [1]. Readers desiring more information about the performance of each system's sensors or how these data were gathered should consult this reference.

Seven SCAS were examined in this study. These systems were designated using letters as Systems A, B, and D through H. (System C was a pre-production prototype that originally was to be included in the study. However, due to delays in obtaining the system, it was not included in this report.)

Table 1 summarizes general characteristics of each SCAS studied. The table shows whether or not each system was a prototype or commercially available, whether or not each system was originally designed for a light vehicle, whether the sensor detection zones covered only the left, only the right, or both sides of the vehicle, and the technology of the sensors. The two rightmost columns show the time that it took for each system to react when an object moving parallel to vehicle entered (Delay Time) or exited (Persistence Time) the sensor's field of view. These columns are shown since they could have a substantial impact on a driver's perception of a warning signal provided by a SCAS. Due to problems with the sensors for System A, delay data were not able to be collected for this system.

TABLE 1. Characteristics of SCAS Studied

SCAS	Prototype System?	For Light Vehicle?	Sides Covered	Sensor Technology	Delay Time	Persistence Time
A	No	No	Right	Ultrasonic	--	--
B	Yes	Yes	Right	Radar	0.07 s	0.51 s
D	Yes	No	Right	Radar	0.52 s	0.12 s
E	Yes	No	Right	Radar	0.62 s	1.23 s
F	Yes	Yes	Both	Infrared	0.04 s	0.92 s
G	Yes	Yes	Right	Radar	0.46 s	0.54 s
H	No	No	Right	Radar	1.03 s	1.80 s

METHODOLOGY USED TO ASSESS THE DRIVER INTERFACES OF EXISTING SCAS

The principal data collection instrument used to perform a human factors evaluation of existing SCAS was a "Human Factors Checklist" titled "Descriptive Profile, Human Factors Assessment, and Operational Judgements of the Collision Avoidance System Driver/System Interface". The checklist was originally developed by COMSIS for NHTSA as part of the heavy truck near object detection system study described in the report titled "A Study of Commercial Motor Vehicle Electronics-Based Rear and Side Object Detection Systems"[3]. The development of the Human Factors Checklist accompanied an effort by COMSIS to define the requirements for driver interface design for collision avoidance systems as outlined in "Preliminary Human Factors Guidelines for Crash Avoidance Warning Devices" [4]. The checklist was modified for this program by R & R Research Inc. and NHTSA's Vehicle Research and Test Center (VRTC). A copy of the checklist used in this study is included as an Appendix to this paper.

In an effort used to reduce the large quantity of data generated by the Human Factors Checklist, a scoring system was used. The scoring system used was originally developed by COMSIS and was modified for use in this program by VRTC.

HUMAN FACTORS CHECKLIST: GENERAL CONCEPTS - The Human Factors Checklist was designed to be used both as a research device and a screening tool. This document served as a tool for the collection of qualitative and quantitative data characterizing SCAS interfaces and their associated visual and auditory information displays and controls.

The checklist was based generally on accepted human factors principles found in handbooks such as "Handbook of Human Factors" [5] and "Human Factors Design Handbook" [6] as well as on accepted automotive practices set forth in the Society of Automotive Engineer's (SAE) Recommended Practices.

However, in many cases, guidelines were lacking in necessary areas important to the design of SCAS driver interfaces. In these cases, guidelines were extrapolated and judgements as to what design features were most appropriate based on the authors' extensive experience testing collision avoidance systems.

The checklist contained three sections. Section A was a descriptive profile which addressed the operation of the system hardware and driver displays. Section B consisted of an assessment of the extent to which the visual and auditory displays conform to established human factors guidelines. Section C consisted of a questionnaire used by human factors experts to assess the design of the driver interface after having driven with the systems. Overall, the checklist provided a means by which the merits of the driver interface could be assessed.

The term "crash avoidance warning" was used during this research to refer to any information which a system provides to the driver to assist in preventing a collision. The information content of the warning is dependent on the category of the system. Crash avoidance warnings are divided into two categories: 1) cautionary and 2) imminent.

Cautionary crash avoidance warning information is any information provided by a system which warns the driver of a potentially dangerous situation (i.e., an obstructing vehicle in an adjacent lane when considering changing lanes). The term "imminent crash avoidance warning information" refers to any information which a system might provide to warn the driver of an impending collision.

Two test vehicles were used in this study: a 1991 Acura Legend and a U.S. Army High Mobility Multi-Wheeled Vehicle (HMMWV). The passenger car, shown in Figure 1, was used to make measurements and gather information for Sections A and B of the Human Factors Checklist for each SCAS. The HMMWV provided for testing, shown in Figure 2, was fitted with an ambulance body. To obtain the data needed to complete Section C of the checklist, both the HMMWV and the Acura Legend were equipped with the SCAS and then driven by two human factors experts The ambient noise levels for both vehicles were recorded at idle and while driving at a speed of 55 miles per hour and with the vehicle windows up and down. Noise readings were taken at the driver ear point. These ambient noise data are listed in Table 2.

TABLE 2. Test Vehicle Ambient Noise Data(dB(A))

	Acura Legend		HMMWV	
Windows	Up	Down	Up	Down
Idle	47.6	49.7	71.6	71.6
55 mph	64.8	69.0	85.0	86.0

SECTION A: DESCRIPTIVE PROFILE - The purpose of the descriptive profile was to record objective information regarding system operation, sensor configuration, and physical and functional characteristics of the visual and auditory driver displays and controls. These data were collected for use in evaluating the appropriateness of characteristics of the driver/system interface. This section was completed for each system by the same human factors expert. Section A of the Human Factors Checklist consisted of two parts: "General Information" and "Checklist of System Features," which were completed for all systems.

The information used to complete Section A was gathered from the documentation provided by the manufacturer (if any) and by examining the systems while they were installed on the Acura Legend test vehicle with the systems operational. Data were collected with the vehicle stationary and in a lab setting. General information was recorded about the systems including the type of sensor technology used, the size of detection zones, and the type of media used for the manufacturer's documentation. Detailed information was collected to define the characteristics of each system's visual and auditory displays.

Measurements of maximum display viewing distances and control reach distances were recorded based upon the manufacturer's suggested location of driver/system interface components. If no suggested location of the interface was provided by the manufacturer, a central location on the dashboard was used. Measurements were also taken to define the physical characteristics of driver-operable controls. A short list of questions was used to determine whether or not systems incorporated certain features.

SECTION B: HUMAN FACTORS ASSESSMENT - The purpose of the human factors assessment was to examine the
extent to which the design of a particular SCAS driver interface conformed to SAE Recommended Practices and accepted human factors design principles. These objective data provided a means for making relative comparisons among systems. Section B of the Human Factors Checklist was completed for all systems.

Section B contained two types of questions. The majority of questions required "yes" or "no" answers. This type of question was used to collect information on cautionary and imminent visual and auditory crash avoidance warnings, visual and auditory system status displays, manual controls, legends, and system documentation. Appropriate responses to these questions

Figure 1. Passenger car used as primary test vehicle (1991 Acura Legend)

Figure 2. HMMWV test vehicle

were determined based on available SAE Recommended Practices and on guidelines and design criteria contained in various human factors references such as "The Handbook of Human Factors" [5] and the "Human Factors Design Handbook" [6]. The second type of question used a 5-point scale to allow the human factors expert completing this section to judge the extent to which SAE Recommended Practices and human factors design principles had been effectively applied to visual and auditory warnings.

The information used to complete Section B was gathered from the documentation provided by the manufacturers (if any) and by examining the systems in operation while installed on the Acura Legend test vehicle. The data for Section B were collected with the vehicle stationary in a laboratory.

SECTION C: OPERATIONAL JUDGEMENTS - Section C consisted of a subjective assessment of each driver interface performed by two human factors experts after having driven with a system over a fixed route. This subjective assessment was completed for all systems. The subjective data collected facilitated the assessment of each system's driver interface from the human factors experts' point of view and provided a means for comparison of this subjective information with objective data collected in other parts of the checklist.

Section C consisted of a two-part questionnaire containing a static evaluation and a dynamic evaluation. Section C was completed for each system eight times according to the following 2 x 2 x 2 matrix:

2 Human factors experts
2 Test vehicles (1991 Acura Legend, HMMWV)
2 Lighting conditions (daytime, nighttime/darkness)

Therefore, each expert completed a total of eight driving sessions with each system.

To complete Section C of the Human Factors Checklist, the experts first reviewed the manufacturer's documentation (if any) and became familiar with the operation of a system through examination of the device with the test vehicle stationary and the system operational. Next, Part I of the questionnaire, which addressed the characteristics of the driver/system interface which could be observed in a static setting, was completed.

The experts then drove the defined test route with a system installed in a test vehicle. The experts drove a defined route in traffic extending between and around East Liberty and Columbus, Ohio in daylight. This route took approximately two hours to traverse and contained equal amounts of driving time on arterial streets, freeways, and rural highways. The route was repeated at night, per the matrix listed above.

Part II of Section C was completed after the test drive had been conducted. In Part II the experts responded to questions based on their driving experience regarding the ease of perception of warning signals, distraction and annoyance experienced, effectiveness of warning presentations, and system use. Questions also were asked to ascertain whether the experts encountered any problems while driving with the system and requested suggestions for possible improvements to the design of the interface and the system as a whole.

PROCEDURES FOR SCORING THE HUMAN FACTORS CHECKLIST

The Human Factors Checklist responses for the SCAS tested contain a considerable amount of data. Scoring was used in an attempt to summarize this large amount of data and assess which driver interfaces had more appropriate features.

Given the state of the art in human factors, the checklist cannot be scored based solely upon information contained in human factors manuals and guidelines. These sources are general guidelines for equipment design and do not provide specific details for SCAS design. Also, handbooks do not cover all design features and do not provide weighting criteria to distinguish the more important guidelines from ones of lesser importance for a particular application. Human factors guidelines were used here to the maximum extent possible to determine the desirable characteristics of a driver interface. However, where there were gaps in the existing guidelines, the authors' judgement based upon experience with a substantial number of these interface was used.

The scoring system only addressed the mostly objective data contained in Section A, Descriptive Profile, and Section B, Human Factors Assessment, of the checklist. Subjective data from Section C, Operational Judgements, were not used.

The scoring system used had six objective categories and one subjective one. The six objective categories were:

1. Overall Design
2. Visual Warning Display Conspicuity
3. Visual Warning Display Comprehensibility
4. Audio Warning Discriminability and Comprehensibility
5. System Status Display Conspicuity and Comprehensibility
6. Control Ergonomics

The one subjective category was Expert Professional Judgement.

A score was calculated for each of the listed categories for each SCAS. A different scoring system was used for each category. However, the same basic technique was used to develop the scoring systems for the individual objective categories.

First, the desirable characteristics of a SCAS driver interface were listed for each category. Then, each listed characteristic of an "ideal" collision avoidance system driver interface was ranked as being either of "high" importance or of "low" or "less" importance. Since no basis is provided in the human factors guidelines to perform this ranking, the authors' judgement was used. Each listed desirable characteristic of a system (e.g., the driver interface included a visual warning display) was then associated with one or more Human Factors Checklist questions. For each question, the response which indicated that the characteristic of the system being evaluated was a desirable one was identified.

Weights were then assigned to each checklist question. Questions associated with desirable interface characteristics that were ranked as being of less importance received one-half the weight of questions associated with desirable interface characteristics that were considered to be of high importance. In cases where multiple questions were associated with one desirable interface characteristic, the weight assigned to each of the multiple questions was reduced. This was done so as to keep the total weight associated with each desirable interface characteristic the same.

Two sums were then calculated for each category. The first sum, Score Weights or W, was incremented by the weight assigned to a question if the answer to the question was the "good" answer. The second sum, Total Weights or T, was incremented by the weight assigned to the question unless the answer to the question was Not Determinable (ND) or Not Applicable (N/A). The score for each category, S, was then calculated by the equation:

$$S = 100 \frac{W}{T}$$

Tables 3 through 8 list the characteristics of an "ideal" SCAS driver interface that were selected for each of the objective scoring categories.

The one subjective category, Expert Professional Judgement, involved a subjective assessment of the driver interface by a human factors expert. The same human factors expert completed Section B of the checklist for all SCAS interfaces evaluated. The Expert Professional Judgement category score was calculated only from questions that were answered using a 5-point rating scale (with five being the highest possible score).

To calculate the score for the Expert Professional Judgement category, each one to five rating scale question in Section B was assigned a weight. One standard weight was used except for cases where two questions were closely correlated. In this situation, to avoid giving a topic too much importance, each question was assigned a weight one-half of the standard weight. Two sums were then calculated for the Expert Professional Judgement category. The first sum, Score Weights or W, was incremented by the weight assigned to a question multiplied by the answer to the question minus one (unless the answer to the question was Not Determinable (ND) or Not Applicable (N/A)). The second sum, Total Weights or T, was incremented by the four times the weight assigned to the question unless the answer to the question was "ND" or "N/A". The score for each category, S, was then calculated by the equation:

$$S = 100\,\frac{W}{T}$$

TABLE 3. Overall SCAS Driver Interface Design Category

Of High Importance:
1. Provides both audio and visual warnings.
2. Has no more than four levels of visual and auditory warnings.
3. Provides warnings whenever vehicle is in motion.
4. Automatically indicates system failure to driver.

Of Less Importance:
5. Has brightness and volume adjustments. These do not allow adjustments below a minimum acceptable level.
6. Does not allow driver to adjust sensor sensitivity.
7. Audio warnings sound only when turn signal on or lane change/merge is being made.
8. Has a temporary manual override control for auditory warnings.
9. Presents no information when no objects sensed.

TABLE 4. Visual Warning Display Conspicuity Category

Of High Importance:
1. Display easy to discern in both daylight and darkness conditions.
2. The display line of sight is near the line-of-sight to the side view mirrors.
3. Line of sight from driver to display is unobstructed.
4. Display easy to discern in light from specular glare sources.
5. The driver can easily discriminate warning display from other displays.

Of Less Importance:
6. Legends are easily legible in daylight and darkness.
7. Driver has unobstructed view of each legend.
8. Legends are easily legible in light from specular glare sources.

TABLE 5. Visual Warning Display Comprehensibility Category

Of High Importance:
1. Information should be organized to be quickly obtained while driving.
2. The information coding techniques used should correspond to population stereotypes (e.g., object present should be designated by a red light).

Of Less Importance:
3. The warning display should be labeled (have legends).
4. Functional legends should be easily discriminated from advertising.
5. Redundant visual information coding should be used.
6. Legends should be near their associated display.

TABLE 6. Auditory Display Discriminability and Comprehensibility Category

Of High Importance:
1. The meaning of auditory warnings is readily apparent.
2. The information coding techniques used should correspond to population stereotypes.
3. The dominant frequency of the tone is between 500 and 3000 Hz.

Of Less Importance:

4. The volume range is from not more than 90 to not less than 60 dB(A).
5. The driver can easily discriminate warning display from other sounds.
6. Complex tones are used for warnings.

TABLE 7. System Status Display Conspicuity and Comprehensibility Category

Of High Importance:
1. Display easy to discern in both daylight and darkness conditions.
2. The display is organized so that the driver can quickly acquire system status information while driving.
3. The information coding techniques used are appropriate for the type of information presented and correspond to population stereotypes.
4. System status display can be easily discriminated from other displays.
5. Driver can easily tell from the display whether or not the system is on.
6. Display easy to discern in light from specular glare sources.

Of Less Importance:

7. The displayed system status information should have a legend.
8. The status display legend should be easily legible in both daylight and darkness.
9. Driver has unobstructed view of each legend.
10. Functional legends should be easily discriminated from advertising.
11. The system status display legend should be easily legible in light from specular glare sources.
12. Legends should be near their associated display.

TABLE 8. Control Ergonomics Category

Of High Importance:
1. Controls are easy to reach and see.
2. Type of control used is appropriate for type of function controlled.
3. Movement of controls corresponds to population stereotypes (e.g., upward, right, or clockwise movements produce an increase in the value of the parameter).
4. Controls are coded for discrimination in blind operation.
5. Use of the control provides appropriate feedback.
6. Controls are separated to prevent accidental activation.

Of Less Importance:

7. Control setting can be discerned via visual or tactile inspection.
8. All controls have legends.
9. All control legends are legible in both day and night lighting conditions.

HUMAN FACTORS CHECKLIST RESULTS BY SYSTEM

The Human Factors Checklist used in this study was modified from its original form developed specifically for use in a study of heavy truck side and rear object detection systems. In modifying this checklist for use in this study, many needed improvements were realized. However, some necessary modifications to the checklist were not realized until the benefit of retrospect was acquired upon completion of the current study.

For this study, human factors experts made multiple test runs in multiple test vehicles in varying conditions of ambient illumination to evaluate each system's driver interface. Since there are a large number of types possible driver interfaces, it is a large and difficult task to create a tool which can be used to evaluate all CAS driver interfaces. While the current version of the Human Factors Checklist is significantly better than the original version, the current research showed that more improvements are needed. Thus, some limitations are present in the current version of the checklist. However, it is reasonable to expect that as intelligent transportation systems become more sophisticated, so must the tool for their evaluation.

In general, the Human Factors Checklist proved to be a very useful tool in this application. The "open-ended" nature of the qualitative questions contained in Part III of Section C facilitated the receipt of interesting comments indicative of the quality of individual SCAS driver interfaces and of system performance. The topics of some of these comments were not addressed in the checklist as used in this study. While the checklist was a very useful analysis tool in this study, the open-ended comments provided ideas for additional questions and topics of interest which should be included in future versions of the checklist. The following discussion of the strengths and weaknesses of individual systems is based primarily on data from Section C of the Human Factors Checklist. The ideas presented were based on responses to the checklist and a consensus of assessments of the human factors experts.

SYSTEM A: HUMAN FACTORS CHECKLIST RESULTS - System A was a commercially available ultrasonic SCAS. This system had a single sensor used to create a detection zone on the right side of the vehicle.

System A: Description of the Driver Interface - System A had two parts to its driver interface. A main display unit, shown in Figure 3, contained both visual and auditory crash avoidance warning displays and visual system status displays. The main display unit was mounted at the center of the dashboard, as shown in Figure 4. Commercial advertising labels were omitted from the photographs. An auxiliary display unit, shown in Figure 5, was mounted at the right A-pillar to provide the driver with an additional source of crash avoidance warning information. The appropriate orientation in which to mount the auxiliary display was assumed since no orientation was specified in the manufacturer's documentation. No controls were present to adjust the brightness of visual crash avoidance warning and system status displays was constant nor the volume of the auditory crash avoidance warning.

On the main display unit was located a crash avoidance warning visual display which consisted of a single red LED labeled “NO TURN!”. This display was located on the far right side of the face of the display unit. This warning light would illuminate steadily (i.e., steady burn, no blinking) whenever an obstacle was present in the detection zone. An additional visual crash avoidance warning display was located at the right A-pillar near the side view mirror. This auxiliary display consisted of a pictorial representation of a roadway complete with lane marking and a red “X” located in the right lane. This red “X” would illuminate in coordination with the visual warning LED on the main display unit to indicate the presence of an obstacle in the right adjacent lane. The system also had an auditory warning which would sound a constant tone whenever an obstacle was present in the detection zone and the right turn signal was activated. System A had two system status displays located on its main display unit. A green LED labeled “READY” which was located at the center of the face of the unit illuminated to provide the driver with an indication that the system was receiving power and operational. A red LED labeled “FAULT” which was located at the far left side of the face of the display unit would illuminate only if the system self test detected a problem with the system hardware.

<u>System A: Strengths and Weaknesses of the Driver Interface</u> - Some problems were observed with the layout of the face of the main display unit. Advertising labels covered a significant area of the face of the display and presented somewhat of a distraction, especially considering the mirror-like quality of the lettering. More importantly, the red “FAULT” LED was rather close to the red warning LED creating the potential for confusion of the driver in terms of determining which display is presenting a signal. In addition, the material covering the face of the display was somewhat reflective causing the potential for glare.

Problems were also encountered with the auxiliary visual warning display mounted at the right A-pillar. The meaning of the symbology of this red “X” display was not obvious to one of the human factors experts who did not understand what the “underscore characters under the X” meant. In addition, this visual display was not bright enough to be seen in all levels of ambient illumination, especially in bright sunlight.

The choice of the color red for the crash avoidance visual displays was appropriate and contrasted well with the green system “READY” LED. The auxiliary visual warning display located at the right A-pillar was found to be helpful. However, there does not appear to be a significant benefit provided by the use of two visual warning displays (i.e., one at the center of the dashboard and one at the A-pillar).

The auditory warning for System A was reported to be both startling and annoying. However, as with many of the systems, the volume of the auditory warning was not loud enough to be heard under all conditions when driving the HMMWV. The presence of a volume control with a reasonable range would alleviate this problem and accommodate individual differences between drivers with differing perceptual capabilities.

Figure 3. System A driver interface: Main display unit

Figure 4. System A main display unit as mounted for testing

The green “READY” LED provided drivers with an indication

Figure 5. System A driver interface: Auxiliary visual warning display

that the system was receiving power and fully operational. This visual display was perceived as being very bright at night and therefore was found to be a source of distraction. The provision of a brightness control for the driver would have alleviated this problem. The red “FAULT” LED was used to indicate system failures to the driver. This display was found to be sufficient, however, it may not be necessary to have separate “system power” and “fault/failure indication”displays. A combined display which would illuminate green when the system is receiving power and operating properly and would change to yellow when a problem was detected with the system hardware may be more suitable. The suggestion of using the color yellow to indicate system failures stems from the desire to make the displays easily distinguishable from one another, and thus making the system failure display a different color than the visual warning display. The choice of green for the system “READY” LED was judged to be very appropriate.

<u>Overall Assessment of the Driver Interface for System A</u> - Many problems associated with the hardware performance of System A were observed which affected the drivers’ use, and in many cases, tolerance, of the systems. Many false alarms and many missed vehicles were encountered with System A which was characterized as having extremely variable performance. The auditory warning was found to be significantly annoying, especially in the passenger car test vehicle which had a lower level of ambient noise in the cab than did the HMMWV. Visual warnings caused by false alarms at night were also found to be annoying to the human factors experts. This problem could be alleviated by designing the sensor hardware to filter out stationary objects to prevent the system from warning the driver of non-threatening objects such as light poles, trees, and guard rail. In addition, warning presentations were noticeably delayed from the time that an adjacent vehicle actually entered the detection zone that the warnings were often considered by the experts to be not useful.

Overall, the design of the display was considered to be largely appropriate and easy to use. The information presented by the displays was found by the experts to be easy to understand, despite the confusion about the meaning of the symbology used in the auxiliary visual warning display. The auditory was determined to be excessively loud for the passenger vehicle application (The system was intended for use in heavy trucks). Some improvements could be made to make the displayed information more easy to perceive in all conditions, such as providing a volume control and a brightness control or automatically controlled brightness with appropriate range.

SYSTEM B: HUMAN FACTORS CHECKLIST RESULTS - System B was a prototype radar-based SCAS intended for use on light vehicles. This system used a single sensor to create a detection zone to the right side of the vehicle.

<u>System B: Description of the Driver Interface</u> - System B had two parts to its driver interface. A control unit, pictured in Figure 6, was mounted at the center of the dashboard in a similar fashion to System A, shown in Figure 4. The crash avoidance warning display, pictured in Figure 7, was mounted at the bottom of the right side view mirror (as in Figure 8).

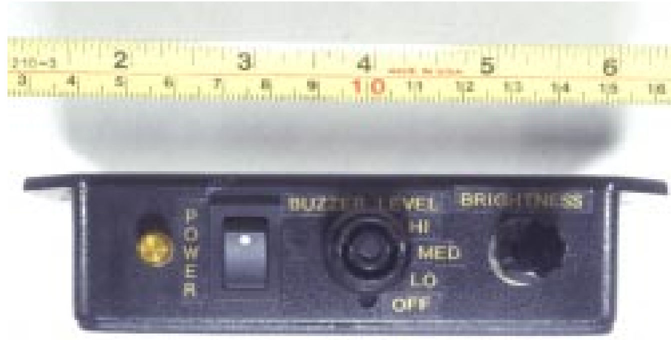

Figure 6. System B main control unit

Figure 7. System B driver interface: Crash avoidance warning visual display

Figure 8. System B crash avoidance warning visual display as mounted for testing

The control unit contained controls for system power, “buzzer level”, and brightness of the crash avoidance warning visual display. A label was provided for each control. This control unit also contained an amber system power LED which was illuminated whenever the system was receiving power.
The crash avoidance warning display was mounted at the bottom of the right side view mirror to provide the driver with crash avoidance warning information while looking at the mirror. This

warning light would illuminate steadily whenever an obstacle was present in the detection zone. The system also had an auditory crash avoidance warning which would sound a constant steady tone whenever an obstacle was present in the detection zone and the right turn signal was activated.

System B: Strengths and Weaknesses of the Driver Interface - The visual crash avoidance warning display was found to be useful and in general not distracting. The color and location of the warning display at the right side view mirror made the warnings easy to understand and easy to perceive. However, some difficulty was encountered in perceiving the visual warning display during the daytime due to insufficient brightness. This fault should be eliminated by increasing the upper limit for adjustment of the brightness level of the visual warnings. Also, the flat surface of the cover of the visual crash avoidance warning display was found to be a significant source of glare in conditions of bright sunlight and therefore was somewhat of a distraction. This problem at times was severe enough that it was difficult to distinguish whether or not the warning display was illuminated. Resolution of this problem may be achieved by replacing the smooth flat cover currently used on the display with a curved one. Overall this visual warning display was found to be simple and appealing.

The design of the auditory warning for System B was found to be easy to understand. The characteristic of the auditory warning being active only when the turn signal was activated is considered to be a good feature. However, one of the human factors experts did report that the pitch of the auditory warning was too high and occasionally was slightly irritating. In addition, the volume of the auditory warning was not high enough to be audible under all ambient noise conditions experienced in the HMMWV. The use of a lower auditory warning tone and continuously adjustable volume control with an increased upper limit of volume would alleviate this problem.

System B provided only visual presentation of system status information. The single system status visual display was found to be sufficient as an indication of the system being powered. However, the color chosen for the display, amber, is considered to be less appropriate for use in indicating to the driver that the system is operating properly than the color green. Since amber or yellow has an inherent meaning of “caution”, the driver may mistakenly assume that the system is indicating a condition of system failure. This system did not appear to provide any indication of system failure. In addition, the flat surface of the power LED was a source of glare in bright sunlight.

The driver interface for System B provided a control which allowed the driver to turn the system on or off at will. Although the design of the control was acceptable, it is believed that the driver should not be given the ability to turn the warning system off. The same principle applies to the use of controls which allow the driver to disable the visual and/or auditory warnings at times when he or she knows an obstacle is present. Controls with this type of function place the responsibility of returning the system to a condition in which it is actively providing warnings on the driver. An alternative method of accomplishing the provision of a way for the driver to “block out” when they are judged to be unnecessary would be to provide a button which would temporarily disable the auditory warnings for a short period of time (e.g., 10 seconds) at times when the driver is aware of an adjacent obstacle and does not require an announcement of its presence. The important idea about this type of control function is that the system would re-activate the warnings on its own, requiring no additional control manipulations by the driver. This function is considered not necessary for visual warning displays since the driver can ignore them or avert visual attention away from the display.

A knob was used to allow the driver to vary the volume of the auditory crash avoidance warnings. Three undesirable characteristics were found to be associated with the design of this control. The design of this control was flawed in that the directions of motion for varying the volume contradicted population stereotypes for this type of operation. The control required the driver to rotate the knob in a counter-clockwise direction to produce an increase in volume of the auditory warning, or conversely, to rotate the knob in a clockwise direction to decrease the volume. The normal convention for the direction of motion of a control used to increase the value of a variable parameter is to rotate the control in a clockwise manner. This problem could be easily remedied by reversing the direction of motion of the control. In addition, only three levels of auditory warning volume were provided. These levels may not be sufficient to accommodate the full range of driver perceptual capabilities and individual differences. Therefore, continuous control of the auditory warning volume, rather than discrete control, would be preferable. Finally, no auditory feedback was provided when adjusting the volume of the auditory crash avoidance warnings. Designing the volume control for the such that a short sample of the warning tone is presented to the driver when the control is manipulated would assist in the setting of the warning volume to a comfortable level.

A third control provided by System B was a brightness control for the visual crash avoidance warning display. The design of this control complied with accepted principles for control design in terms of direction of motion and shape of the control (it was visually distinguishable from the volume and power controls). However, three design problems were identified. First, the control was not distinguishable from the volume (“buzzer level”) control in a tactile sense. The provision of control shape features which allow the driver to distinguish between controls by touch facilitates ease of control discrimination in blind operation (e.g., in darkness, at night). Placing more distance between the brightness and volume controls would also assist in their blind operation as well as assist in preventing their inadvertent activation. Secondly, no indication of control status was provided to allow the driver to visually determine the status of the control setting. Providing markings on the display to indicate the minimum, maximum and median of the adjustable range of the control would be helpful to the user. Lastly, no visual feedback was provided when adjusting the brightness of the visual crash avoidance display unless a warning was being given at the time the brightness was being adjusted. This meant that the driver could not adjust the brightness of the visual crash avoidance warnings before initiating travel, but rather would have to wait until an obstacle was encountered which activated the visual warning display in order to adjust the brightness of the display to an acceptable level. This problem could be alleviated by activating the display when the brightness control is manipulated to allow the driver to observe the intensity of the visual warning display or to provide a “push-to-test” button which would allow the driver to activate the visual and auditory crash avoidance warnings for a short time (e.g., 5 seconds) and observe the effects of control manipulation in adjusting the levels of the displays and ensure that the levels are acceptable and facilitate quick perception of crash avoidance warnings.

The functions of each of the three controls contained in the driver interface were identified through the use of adhesive labels. These labels were sufficiently easy to read, but were found to be susceptible to glare in conditions of bright sunlight. Also, the labels were not backlit for viewing in conditions of darkness and thus were not sufficiently visible at night.

<u>Overall Assessment of the Driver Interface for System B</u> - The overall design of System B was judged by the experts to be simple and straightforward. The crash avoidance warning information provided by the system was judged to be easy to understand, but not always useful since the sensor hardware did not filter out stationary objects and therefore produced many unnecessary warnings. These unnecessary warnings were primarily visual, since the auditory crash avoidance warning was only active when the turn the signal was activated. The unnecessary visual warnings were found to be a source of annoyance, especially at night. However, the cause of this annoyance is considered to be a sensor problem not an interface one. Overall, the human factors experts found the design of the driver interface to be appropriate and acceptable.

SYSTEM D: HUMAN FACTORS CHECKLIST RESULTS - System D was a prototype Doppler radar-based SCAS. This system had a single sensor used to create a detection zone located to the right side of the vehicle.

<u>System D: Description of the Driver Interface</u> - The driver interface for System D consisted of a single display unit, shown in Figure 9. Commercial advertising labels have been omitted from the photographs.

System D had one system status display. The display consisted

Figure 9. System D driver interface

of an amber LED labeled “power” which would illuminate to indicate that the system was receiving power. One control was present on the face of the display unit. This control was required to be adjusted to one of two settings during the initial configuration of the sensor hardware, and was not intended for use by the driver during normal operation.

The crash avoidance warning information visual presentation for System D had two parts. The first part consisted of three LEDs aligned vertically at the center of the face of the display unit which were used to alert the driver to the presence of an adjacent obstacle and its direction of motion with respect to the subject vehicle (i.e., the vehicle on which the system is installed). The amber-colored LED labeled “target” was used to indicate that an object was present in the detection zone. If a detected adjacent vehicle was going faster than the subject vehicle, the red LED labeled “closing” would illuminate in addition to the “target” LED. Similarly, if a detected adjacent vehicle was traveling at a slower speed than the subject vehicle, the green LED labeled “receding” would illuminate in addition to the “target” LED.

The second part of the crash avoidance warning visual display consisted of an LCD “speed” display located on the left half of the face of the display unit. This display would present the speed of the subject vehicle when no objects were detected by the system (i.e., the “target” LED was off) and would display the speed of the detected vehicle when an adjacent vehicle was present (i.e., the “target” LED was illuminated).

System D also had an auditory warning which would sound a constant high-pitched tone when a detected adjacent vehicle was traveling at least 10 mph faster than the subject vehicle.

<u>System D: Strengths and Weaknesses of the Driver Interface</u> - The LEDs composing the crash avoidance warning visual display were reported to be too bright during nighttime driving conditions. The red “closing” LED was reported to be especially bright and distracting at night. The “target” LED which indicated that an adjacent vehicle had been detected was the same color (amber) as the power LED presenting a potential source of confusion. The choice of the color green for the “receding” LED which was part of the crash avoidance warning visual display was considered to be inappropriate. Furthermore, the need for the “closing” and “receding” was questioned and preliminarily judged to be unnecessary.

The human factors experts reported that while driving with System D the visual crash avoidance warning LEDs would flash only momentarily to indicate the presence of an adjacent vehicle in the detection zone. The excessively short duration of the visual warning presentation was considered to be a disadvantage. In addition, the visual warnings LEDs would continue to flash erratically for some seconds after a vehicle had exited the detection zone creating a situation for potential driver confusion and lack of confidence in the warning presentation.

The LCD speed display was considered to be an unnecessary source of confusion for this SCAS. The display would present the actual speed in miles per hour of an adjacent vehicle when one was present and would present the speed of the subject vehicle when no adjacent vehicle was detected. However, it was not obvious when the display switched from displaying the speed of the subject vehicle to displaying the speed of an adjacent vehicle. Due to the confusion associated with this speed display and the lack of a good reason for its presence, it was considered unnecessary.

The auditory warning for System D consisted of a constant high-pitched tone which was presented when a detected adjacent vehicle was traveling at least 10 mph faster than the subject vehicle. The nature of the auditory warning and the conditions which triggered its presentation were not obvious since no documentation was provided with the system. The lack of information about this auditory warning which provided different information than the visual crash avoidance warning displays caused some confusion for the human factors experts when driving with the system. In addition, the human factors experts reported that the volume of the auditory crash avoidance warning was not high enough to be heard while driving the HMMWV which produced extremely high levels of ambient noise in the cab ranging from 71.6 to 86 dB(A). The use of a volume control with a reasonable range would contribute to eliminating this problem.

System D had one system status display which provided the driver with an indication that the system was receiving power. Since this display presented only an indication that the system was in operation and provided no indications of system failure or any other type of information, it was judged that a more appropriate color for the display would have been green.

A single control labeled "front/back" was present on the face of the display unit. This control was used in the initial configuration of the sensor hardware and was not intended for use by the driver. Since this control was not intended for use by the driver, but was intended for installation purposes only, it was not appropriate for the control to be located on the face of the display unit.

Overall Assessment of the Driver Interface for System D - Overall, the driver interface for System D was confusing. The information presented by the system seemed to be more than was necessary. The LCD speed display was judged unnecessary. In addition, the need for provision of directional information regarding the motion of a detected vehicle was questioned. The human factors experts considered the presentation of this information to be confusing and unnecessary. However, a detailed analysis of the needs of the driver in terms of what information is necessary for the driver to effectively avoid lane change/merge collisions should be performed.

The area of the face of the display unit surrounding the visual displays was reflective and created a source of glare in bright sunlight. The exterior housing of the system also reflected sunlight causing distraction and annoyance of the driver.

Despite the many problems associated with the driver interface for this system, System D did have a major advantage over other systems. This advantage was the capability of the sensor hardware to filter out stationary objects. This capability somewhat reduced the incidence of unnecessary warnings, but the reduction was not pronounced because of other problems with the sensor hardware. A downfall was associated with the method used to filter out stationary objects in that in accomplishing this function also ignored objects traveling at exactly the same speed as the subject vehicle. This method creates the potential for collision in the event that an adjacent vehicle that the driver is not aware of is traveling at the same speed as the subject vehicle.

In summary, the driver interface for System D requires significant modifications to simplify and improve the exchange of information with the driver.

SYSTEM E: HUMAN FACTORS CHECKLIST RESULTS - System E was a prototype radar-based SCAS. This system had a single sensor used to create a detection zone located to the right side of the vehicle.

System E: Description of the Driver Interface - The driver interface for System E consisted of a single display unit intended for use in heavy trucks, shown in Figure 10. The display unit was mounted at the center of the dashboard, similarly to that shown for System D in Figure 4. Commercial advertising labels have been omitted from the photograph.

System E had one system status display. The display consisted of an green LED labeled "PWR" which would illuminate to indicate that the system was receiving power.

The crash avoidance warning visual displays for System E were only partially used since this system and its driver interface were intended for use in heavy trucks with trailers. The red LED labeled "CAB" was used to indicate that an obstacle had been detected. The LED labeled "TRLR" (trailer) was not used in this passenger car application and was inoperable during testing. The "CAB" LED would remain illuminated as long as the presence of an obstacle was detected.

This system also had an auditory warning which would sound a constant high-pitched tone when an adjacent vehicle was detected and the right turn signal was activated. A toggle switch labeled "BP" allowed the driver to switch between having the auditory warning operational at all times or only when the turn signal was activated.

<u>System E: Strengths and Weaknesses of the Driver Interface</u> - The visual crash avoidance warning display was not sufficiently conspicuous during daytime driving due to insufficient brightness of the LED and glare. The warning LED was also too directional and required direct glances perpendicular to the face of the display in order to adequately perceive a visual warning signal. The visual warning LED also remained illuminated for a significant period of time after an adjacent vehicle had left the detection zone causing some confusion for the experts while driving with the system.

The auditory crash avoidance warning for System E was reported by the experts to be both "painfully loud" and "piercing". The pitch of the warning tone was considered to be excessively high, thus causing driver discomfort and annoyance. The use of a lower tone for the auditory warning combined with a volume control would significantly improve the current design.

The use of the color green for the system status LED labeled "PWR" was considered appropriate. However, due to insufficient brightness, difficultly was encountered when trying to discern whether or not the LED was illuminated in conditions of high ambient illumination. This LED was also judged to be too bright for nighttime operation and was a source of annoyance for the driver. The use of a brightness control should alleviate this problem.

The sensor selection rotary knob (used to allow selective sensor activation in the multiple-sensor heavy truck application) was unnecessary for this passenger car application since only one sensor was used. The meanings of the labels for this control were reported to be unclear.

The toggle switch labeled "BP" was allowed the driver to switch between having the auditory warning operational at all times or only when the turn signal was activated. The orientation of this toggle switch should have been vertical rather than horizontal to agree with accepted human factors principles.

<u>Overall Assessment of the Driver Interface for System E</u> - Overall, the driver interface for this prototype was judged to need a variety of general refinements to make the interface more effective and user-friendly. The visual crash avoidance warning displays required modifications to make them more perceptible in a wide range of ambient light conditions. The tone of the auditory alarm was unnecessarily high. Some of the problems with the auditory warning could have been solved with a volume control. In general, the driver interface for System E needs many refinements before it should be released as a commercial product in order to make it more effective.

SYSTEM F: HUMAN FACTORS CHECKLIST RESULTS - System F was a prototype infrared-based SCAS intended for use on both light and heavy vehicles. This system had left and right side sensors creating detection zones on both sides of the vehicle.

<u>System F : Description of the Driver Interface</u> - The driver interface for System F consisted of two identical crash avoidance warning visual display units like the one pictured in Figure 11. One display unit received signals from the left side sensor and was mounted vertically at the left A-pillar as pictured in Figure 12. The other received signals from the right side sensor and was mounted on the right A-pillar in a similar fashion. Both of the visual display units contained a blue system status LED located at the top of the display. This LED would remain illuminated to indicate that the system was receiving power and would turn off if the system detected an internal failure. Visual crash avoidance warning information was presented by three yellow LEDs located on the lower half of the display unit. These LEDs illuminated simultaneously to indicate that an obstacle had been detected adjacent to the vehicle. An opening in the center of the visual display unit housed a light sensor which measured ambient illumination levels and automatically adjusted the intensity of the LEDs accordingly. The system had no auditory warnings of any kind.

<u>System F: Strengths and Weaknesses of the Driver Interface</u> - The visual crash avoidance warnings for this system were considered to be well located and very visible when pointed directly at the driver. However, this visibility was significantly reduced if the axes of the LEDs were not exactly aligned with the driver's line of sight. This "highly directional"

Figure 10. System E driver interface

Figure 11. System F driver interface

Figure 12. System F driver interface: left side visual display as mounted for testing

quality of the display LEDs is expected to be somewhat problematic with wide spread use of this type of visual warning display because the display must be aligned for a particular driver in order for it to be sufficiently visible and must be realigned for different individuals driving the same vehicle. Some method of moving the LEDs to adjust their direction such that it lines up with the driver's line of sight must be provided, much like the control of the position of a side view mirror in a passenger vehicle.

The use of yellow for the crash avoidance warning visual displays is considered to be less appropriate than red for this type of system. The color red has inherent meaning for the general population and therefore is believed to be a more effective way to present this type of warning information. The use of three separate LEDs to present the same warning message simultaneously is also questionable. Some confusion was experienced by the experts initially in determining whether these three LEDs presented three separate pieces of information to the driver or whether they were intended to constitute a single display. The latter was deduced to be the apparent function of the display. Since the three LEDs were designed to illuminate simultaneously to present a visual warning, confusion might be reduced by combining them or placing a cover or shield over the LEDs to make them appear to the driver as a single display.

The visual crash avoidance warning displays were found to excessively bright at night and presented somewhat of a distraction to the driver. These LEDs were also found to be too dim for sufficient viewing in bright sunlight.

This system had no auditory crash avoidance warning displays. This lack of an auditory warning display was considered to be a disadvantage. Accepted human factors principles suggest the use of redundant visual and auditory displays for the presentation of warning information. In order to prevent distraction and annoyance of the driver by presenting auditory warnings when the driver is not intending to change lanes, the preferred method of implementing an auditory warning for this type of system would be to design it to be active (i.e., in a mode to produce warnings) only when the turn signal is activated.

The driver interface for System F contained a visual system status display within the crash avoidance warning display mounted at the left and right A-pillars. This blue LED was positioned above the three yellow crash avoidance warning LEDs as pictured in Figures 3.10 and 3.11. This LED was judged to be too dim for easy viewing in daytime lighting conditions and too directional. This display caused some degree of initial confusion for both human factors experts who could not figure out what this blue LED was supposed to mean. (No user's manual was available for this system.)

The use of this display as an indication of system status at the A-pillars with the crash avoidance warning display was considered to be a good design feature, although it somewhat contradicts information presented in [4]. The presence of this display was found to be especially helpful at night when ambient illumination levels were low because it expedited the driver's visual search for the warning display. If the display was not present, when preparing to make a lane change the driver might spend some seconds visually searching for the warning display in the darkness when the warning light is not illuminated. The use of the status LED assisted the driver in quickly locating the visual warning display in darkness. An improvement to this design feature would be to illuminate a yellow LED, rather than a blue one, at the A-pillar to indicate that no vehicle is detected but that the driver should proceed with caution. In the same fashion, the use of a red LED, rather than a yellow one, is considered more appropriate for the presentation of a collision warning, especially in situations in which a collision is imminent [3]. The yellow LED should not be illuminated when the red visual warning LED is illuminated. This yellow LED could also be used to present system status information by flashing to indicate that a problem has occurred with the system hardware.

The use of the color blue for a system status display was considered to be less appropriate than the color green which is suggested for use in relating a “system ready” condition which was the intent of this display. However, the color green would not be appropriate for use to present system status information at the A-pillar as part of the warning display as this system was configured. The important point is that a green light should not be used in any way that it could be misconstrued as meaning that the adjacent lane is clear (e.g., the blue light as used in this system should not have been green).

The driver interface for System F had no controls associated with it. The provision of a control to allow the driver to change the brightness of the visual displays would have been helpful.

<u>Overall Assessment of the Driver Interface for System F</u> - System F was the only system tested in this study which had both right and left side sensors and crash avoidance warning visual displays for detecting and presenting information relating to adjacent vehicles. This was considered to be a very favorable feature for this type of system and was praised by the experts. The use of a left side sensor is also believed to be especially appropriate for this passenger car application based upon the nature of the lane change merge accident problem for passenger cars. The use of a light which is present when no objects are sensed in the detection zones was very helpful at night. However, the color of this light (blue) and the yellow color used for the visual crash avoidance warning were inconsistent with population stereotypes. The extremely directional quality of the display LEDs was also found to be a drawback.

SYSTEM G: HUMAN FACTORS CHECKLIST RESULTS - System G was a prototype radar-based SCAS. This system had a single sensor used to create a detection zone located to the right side of the vehicle.

<u>System G: Description of the Driver Interface</u> - The driver interface for System G consisted of a single display unit, shown in Figure 13. The display unit was mounted at the center of the dashboard. Commercial advertising labels have been omitted from the photograph.

Crash avoidance warning information presentation was presented visually using a single red LED labeled “STOP”. This LED would remain illuminated as long as the presence of an adjacent obstacle was detected. This system also had an auditory warning which would sound a beeping tone when an obstacle was present to the right side of the vehicle. A toggle switch was present which allowed the driver to disable the auditory warning at will. When the auditory warning was disabled, the visual display continued to function normally.

System G had one system status display. The display consisted of a green LED labeled “OK” which illuminated to indicate that the system was receiving power. A third display (“WARN”) was inoperative due to a design change made by the manufacturer.

<u>System G: Strengths and Weaknesses of the Driver Interface</u> - The visual warning display for System G consisted of a large red LED labeled “STOP”. The choice of the color red for use in this display was considered to be most appropriate. However, this LED was highly directional and thus was difficult to discern whether or not it was illuminated unless the face of the display was perpendicular to the driver’s line of sight. The silver bezels around the LEDs were a source of glare in bright sunlight. The red warning LED was excessively bright in darkness. The provision of a brightness control for the driver to adjust the intensity of the visual displays may have alleviated this problem. The provision of a crash avoidance warning visual display at the right mirror would have been helpful.

Labels for the visual displays were not backlit and thus were difficult to read in conditions of low light. These labels were reflective and a source of glare in bright sunlight.

The human factors experts found the pitch of the auditory warning tone to be too high. This tone was considered to be both annoying and distracting, especially due to the frequent incidence of unnecessary warnings produced by the system.

The green light labeled “OK” provided the driver with a simple indication that the system was powered and functioning. However, this LED was highly directional and thus was difficult to discern whether or not it was illuminated unless the face of the display was perpendicular to the driver’s line of sight. This driver interface did not appear to provide any indication of system failure to the driver.

The toggle switch provided which allowed the driver to disable the auditory warning status was too small. In addition, the direction of motion of this control was not in accordance with population stereotypes. The provision of volume and brightness controls would have been beneficial.

<u>Overall Assessment of the Driver Interface for System G</u> - Although the design of this driver interface incorporated the appropriate use of color and legends, the directional quality of display LEDs and the display’s proneness to glare proved to be significant disadvantages. The use of brightness and volume controls would benefit this design. This driver interface also was found to emit a high-pitched sound while the system was powered which was a source of annoyance and discomfort to one of the human factors experts who participated in the testing.

Figure 13. System G driver interface

Figure 14. System H driver interface: Main display unit

Figure 15. System H driver interface: A-pillar crash avoidance warning visual display

Overall, this driver interface needs much refinement before the system is released as a commercial product in order for drivers to use the system effectively.

SYSTEM H: HUMAN FACTORS CHECKLIST RESULTS - System H was a commercially available radar-based side and forward collision avoidance system. This system had a single right side sensor used to create a detection zone adjacent to the vehicle. The forward-looking collision avoidance capability of the system was not exercised in this study.

System H: Description of the Driver Interface - System H had two parts to its driver interface. The main display unit, shown in Figure 14, was mounted at the center of the dashboard, as is shown for System A in Figure 4. Commercial advertising labels have been omitted from the photographs. An additional crash avoidance warning display unit, shown in Figure 15, was mounted at the right side A-pillar and provided the driver with right side crash avoidance warning information.

The main display unit contained both system status displays, controls, and visual crash avoidance warning displays for the forward-looking sensor. System status displays included a green LED labeled "ON" which illuminated to indicate that the system was receiving power. Also present was a red LED labeled "FAIL" which illuminated to indicate that a system hardware failure had occurred. The remaining visual displays present on the face of the display unit were associated with the forward-looking sensor which is not addressed here. A control was present on the left side of the display which allowed the driver to turn the system on or off and also to control the volume of the auditory warning. The control on the right side of the face of the display unit was associated with the forward sensor. This system adjusted the brightness of all visual displays automatically to accommodate changing levels of ambient illumination.

The visual crash avoidance warning display for side-looking sensor was located at the right A-pillar near the side view mirror. At the bottom of this display was a yellow LED which illuminated to indicate that no obstacles were present in the detection zone. When an obstacle was detected by the system, a red LED located at the top of the crash avoidance warning display unit would illuminate steadily. The component located between the two LEDs just described was actually a light sensor used to sense the level of ambient illumination and adjust the brightness of the crash avoidance warning displays accordingly.

The system also had an auditory warning which would sound a short chime when an obstacle was present in the side detection zone and the right turn signal was activated.

System H: Strengths and Weaknesses of the Driver Interface - The design of the crash avoidance warning visual displays for System H was considered to be good and in accordance with the design characteristics suggested later in this report, i.e., a yellow LED was used to relate to the driver that no adjacent vehicle was detected but that he or she should proceed with caution and a red LED was used to indicate that an adjacent vehicle had been detected. However, the human factors experts found that the LEDs used to present crash avoidance warning information were highly directional and not bright enough to be sufficiently visible while driving in darkness. This problem was considered correctable and not inherent to the interface design.

The light sensor used to measure ambient light levels and perform automatic brightness control of the visual warning displays was considered a potential for confusion of the driver. The reason for this is the light sensor looked like a non-functioning visual warning LED due to its shape and position between the yellow and red warning LEDs.

Another interesting phenomenon regarding the automatic brightness adjustment feature of this driver interface was observed while driving on a lighted highway in darkness. One human factors expert found that when driving under street lights on the highway, the brightness of the visual warning LEDs would change depending on the position of the vehicle with respect to the street light (i.e., under a street light, between two of them, etc.). Due to the nature of the system's abruptly discrete adjustment of the brightness of the displays, the LEDs appeared to be flashing when driving on this type of lighted roadway. This feature proved to be a source of confusion and annoyance for the driver.

The crash avoidance warning auditory display used a signal consisting of a short chime which was found to be easy to perceive and discern. The adjustability of the auditory warning volume via the provided control ensured that the warning signal could be heard in a wide range of ambient noise levels. Auditory warning were only provided when the turn signal was activated which was considered to be a good feature.

The system status visual displays for System H showed an appropriate use of color with green being the color of the "ON" display and red the color of the "FAIL" display. The legend for the system status visual display would have been more easily visible if they were provided as separate larger sized text placed appropriately with respect to the warning light rather than using small text superimposed on a shield covering the warning LED.

The volume control provided by System H was considered to be very good in that it provided auditory feedback reflecting the setting of the volume level as the driver manipulated the control. The auditory feedback consisted of the system sounding the short auditory warning chime at short intervals while the volume knob was being rotated by the driver. The legends used to label the controls present on the driver interface were considered to be good. However, it was not obvious without studying the driver manual thoroughly that the range control located on the right half of the face of the display was for the forward-looking sensor (not tested in this study).

<u>Overall Assessment of the Driver Interface for System H</u> - Overall, the driver interface for System H was considered to be good. The appropriate use of color for visual displays, method of providing visual warnings, and location were all considered to be good qualities of this interface. Other favorable qualities included a good auditory warning signal which was active only when the turn signal was applied and a very well-designed volume control function which provided auditory feedback to the driver. An improvement to this driver interface would the improvement of the automatic brightness control feature or the use of a manual brightness control. The only significant faults of this system, which were observed in this human factors testing but apply to the hardware of the systems, were the noticeably long delay time in presentation of crash avoidance warnings and small detection zone.

HUMAN FACTORS CHECKLIST RESULTS -- BETWEEN SYSTEMS COMPARISONS

This section contains the results of between systems comparisons for the different SCAS. Most of the analyses contained in this section are based on data from Section C of the Human Factors Checklist. At the end of the section, the results of the scoring that was performed on Sections A and B of the Human Factors Checklist are presented.

The results presented graphically for Section C of the Human Factors Checklist were based solely on the responses of the two human factors experts after having driven with the SCAS. Although responses were based on basic human factors principles and related expert professional judgements, some degree of individual differences are present in the data. In addition, although questions contained in the checklist focused on assessing the attributes of the driver interface, frequently it was found that factors related to system performance had some effect on the perceived effectiveness of the driver interface designs. Inconsistent or variable system performance could be attributed to weather, mechanical problems, or some other cause. Due to the inconsistent performance observed for many of the systems tested and the small sample size used, it is difficult to attribute variability in response data to any one source. In some cases, the differences in responses due to individual differences may be larger than the differences between the plotted data values. Therefore, the response data are not discussed as being statistically significant. However, in many cases, the data do show trends which allude to the effectiveness of individual SCAS driver interface designs.

The data values listed in the following figures represent the means of the responses obtained for individual questions during the eight driving sessions (2 human factors experts; 2 test vehicles; day and night) conducted under Section C of the checklist for each system. Each driving sessions lasted approximately 2.5 hours.

The issues addressed were ones whose impacts were judged to be likely to contribute significantly to the utility and potential degree of benefit provided by the systems, i.e., the degree to which the systems contribute to decreasing the likelihood of a collision, or the degree to which they improve safety. Areas judged to be important for inferring the utility and ease of use of systems through "in-use" evaluation included the comprehensibility of the crash avoidance warning displays (see Figure 16), the ease with which crash avoidance warning displays could be discriminated from other in-vehicle displays (see Figure 17), the degree to which the visual and auditory displays associated with a system were a source of distraction or annoyance to the driver (see Figures 18 through 21), the perceived degree of effectiveness of the systems (illustrated in Figures 22 through 25), and how often the system was used (shown in Figures 26 and 27).

Two questions contained in the checklist addressed the adequacy of manufacturer supplied documentation describing the operation of the SCAS. Only 3 of the 7 systems had associated documentation. Only one of those provided was very good, while the others were barely adequate.

Some displays were simple enough that their meanings could be easily deduced in a static setting. Others, as shown by the results of the human factors experts' static assessment of the meaning of crash avoidance warning visual displays for SCAS given in Figure 16, were not so easy to determine (e.g., the meaning of a blue light at the right A-pillar which illuminated constantly and was extinguished when a yellow light was illuminated). Overall, it was clear that complete descriptive documentation detailing the operation of the SCAS and the function of all visual and auditory displays was essential for proper and effective use of the system.

Figure 17 shows that, although the crash avoidance visual warnings for most systems could be easily identified, the driver interfaces for Systems D and F had designs which were confusing in terms of distinguishing between crash avoidance warning visual displays and system status visual displays. A common problem encountered with the systems tested was the inappropriate use of color in visual warning and system status displays. Overall, the system status displays for the driver interfaces tested were not significantly distracting in most cases as shown in Figure 18. However, the visual displays used to present system status information for some systems were considered to be excessively bright for nighttime driving.

Distraction presented more of a problem for some crash avoidance warning visual displays, as illustrated in Figure 19. The data presented in this graph corresponds well with the qualitative assessments of systems characteristics obtained in Part III of Section C of the Human Factors Checklist. The driver interface for System D, which rated a relatively low score for this measure, was considered to be confusing by the human factors experts and was judged to present too much information to the driver. The warning LEDs for this system were also reported to be excessively bright for nighttime driving applications.

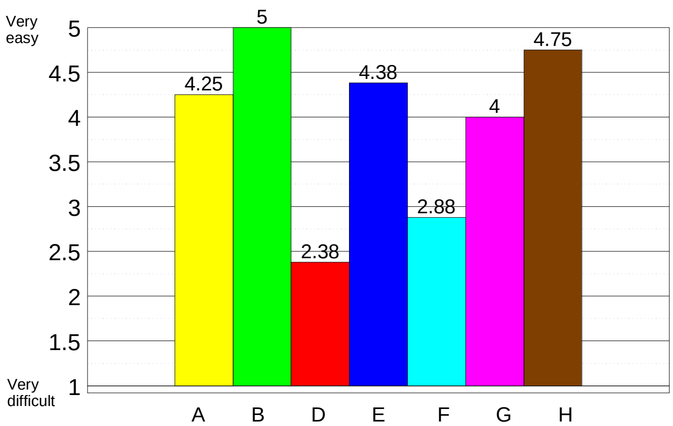

Figure 16. Part I, Question 5c: How easy to understand are the meanings of the cautionary crash avoidance warning visual displays?

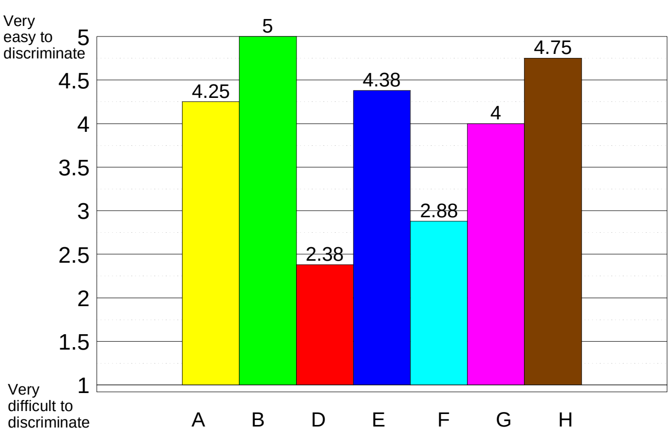

Figure 17. Part II, Question 3: While driving, how well could crash avoidance warning visual displays be discriminated from any other nearby displays?

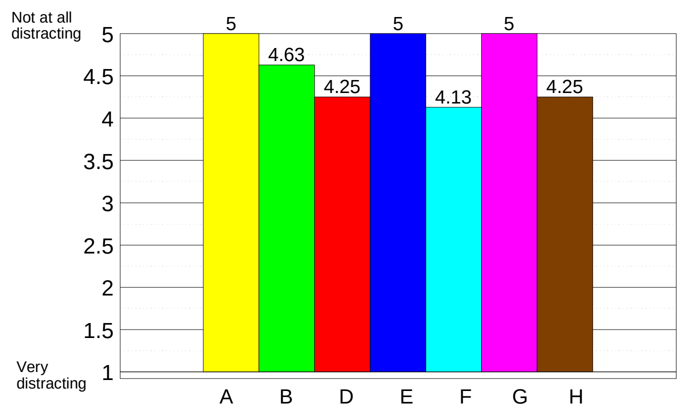

Figure 18. Part II, Question 4a: While driving, how distracting were the visual system status displays?

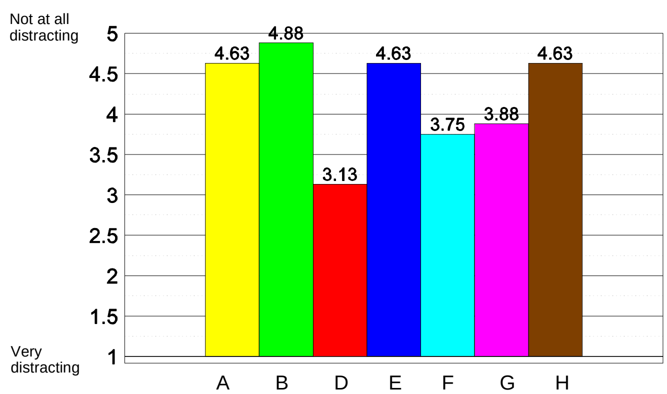

Figure 19. Part II, Question 5b: While driving, how distracting were the auditory crash avoidance warning displays?

Systems F and G were also considered to be distracting due to excessively bright LEDs. This finding may be misleading for System F whose LEDs varied in apparent brightness depending on the angle at which they were viewed. Due to the nature of the type of LEDs used in the warning display for System F, if the display was not positioned such that the driver's line of sight was perpendicular to the LED, the illumination could be difficult to distinguish in some light conditions.

Distraction due to crash avoidance warning auditory displays was noted to be more of a problem for the human factors experts, as shown in Figure 20. Three of the six SCAS (System F had no auditory warning display) were rated relatively poorly in this area. The auditory warning display for System E, which was characterized by the human factors experts as "shrill" and "piercing," received the lowest rating.

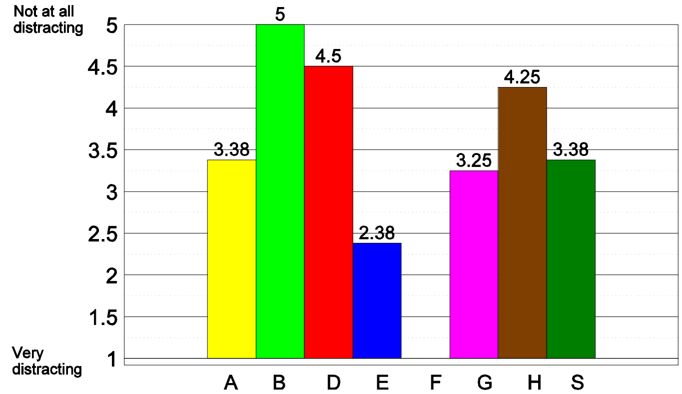

Figure 20. Part II, Question 5b: While driving, how distracting were the auditory crash avoidance warning displays?

The scores for the level of annoyance caused by the auditory crash avoidance warning displays, shown in Figure 21, correlate fairly well with the level of distraction data presented in Figure 20. The results show that certain of the systems examined require significant improvements to their auditory warning displays in order to make them more user-friendly and appealing, or at least tolerable, for drivers.

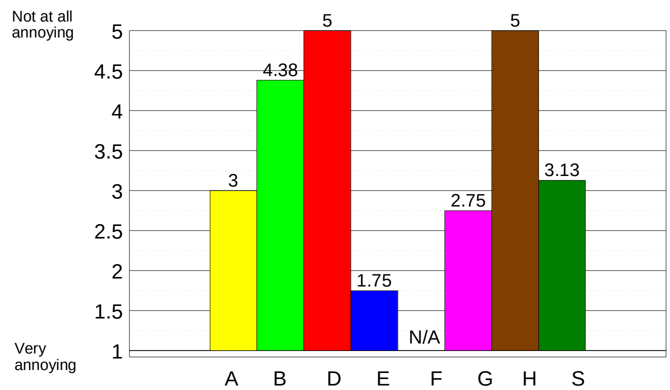

Figure 21. Part II, Question 6b: While driving, how annoying were the auditory crash avoidance warning displays?

A question which was considered to be one of the most important ones in the checklist addressed the effectiveness of the collision avoidance systems tested. Data regarding the effectiveness of crash avoidance visual warnings are illustrated in Figure 22. Only minimal differences in the mean ratings of effectiveness for lane changes was observed between the two vehicles. This is surprising given the large size of the right side blind spot area on the HMMWV as compared to the Acura Legend used in the testing. These minimal differences in the mean ratings do not correspond to the qualitative responses of the human factors experts obtained in Section C of the checklist. These data do correspond well with the scores which systems received in the categories of Visual Conspicuity and Visual Comprehension that are listed in Table 9.

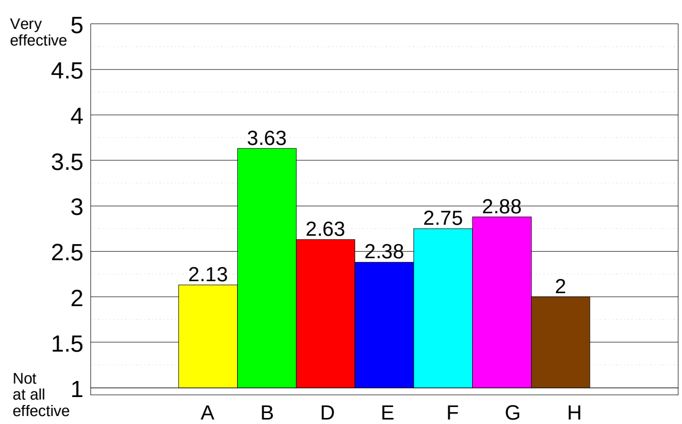

Figure 22. Part II, Question 9a: How effective was the visual crash avoidance warning display in helping you to make right lane changes?

Ratings of the effectiveness of visual crash avoidance warnings in helping drivers to make right merges are given in Figure 23. These ratings are not significantly different from those obtained in regards to effectiveness of systems for helping drivers to make right lane changes. The information required by the driver to perform right merges is basically the same as that required for a driver to safely perform right lane changes. Therefore, the same type of visual display used for performing right lane changes should be suitable for right merge situations as well. However, the area in which the SCAS detects obstacles needs to be different for the merging application in order to accommodate the greater distance and angle of approaching traffic.

Similar results as those obtained in regards to visual warning displays were observed for the ratings of the effectiveness of auditory crash avoidance warnings in helping drivers to make right lane changes. The results for the effectiveness of auditory crash avoidance warnings in right lane change applications, illustrated in Figure 24, show no significant differences from those obtained for right merges shown in Figure 25. These auditory warning displays are thought to require the same type information presentation to the driver whether the application is lane changes or merges, as was the case for visual crash avoidance warning displays.

Also of interest was whether or not the human factors experts involved in this study actually used the systems during the required test driving portions of the interface evaluations performed using the Human Factors Checklist. The experts estimates of their frequency of system usage are illustrated in Figures 26 and 27. However, these data should examined with the consideration that the experts drove no more than a total of 10 hours with each SCAS. In addition, although the question asked how often the system was used during maneuvers of interest, it does not address whether or not the use of the system actually assisted the driver in safely performing the maneuver. The response data are also inherently related to system performance. The reason for this is that if a system was performing particularly poorly during a certain test driving session, then the driver would use the system less often. A fair degree of variability was observed due to inconsistent system performance for many of the systems.

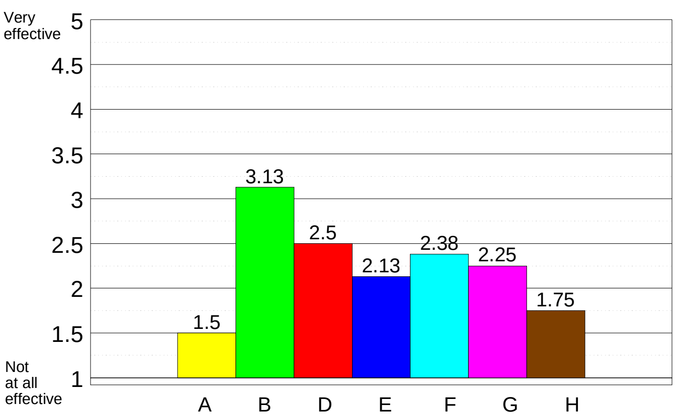

Figure 23. Part II, Question 9a: How effective was the visual crash avoidance warning display in helping you to merge to the right?

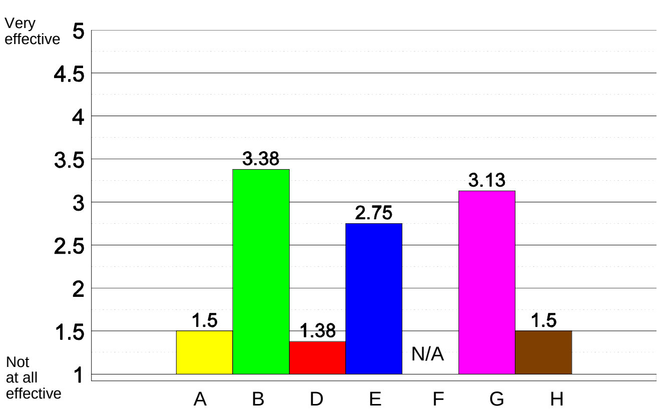

Figure 24. Part II, Question 12a: How effective was the auditory crash avoidance warning presentation in helping you to make right lane changes?

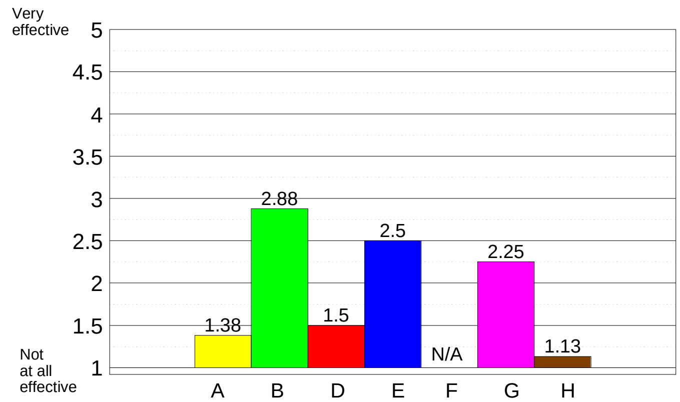

Figure 25. Part II, Question 13a: How effective was the auditory crash avoidance warning presentation in helping you to merge to the right?

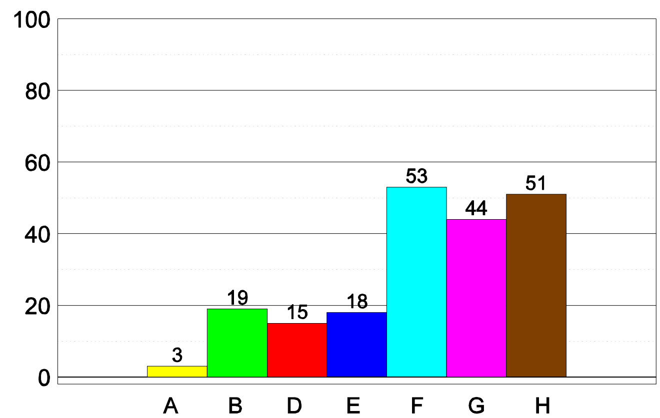

Figure 26. Part II, Question 14: In what percent of all lane changes did you use the crash avoidance warning information presented by the system?

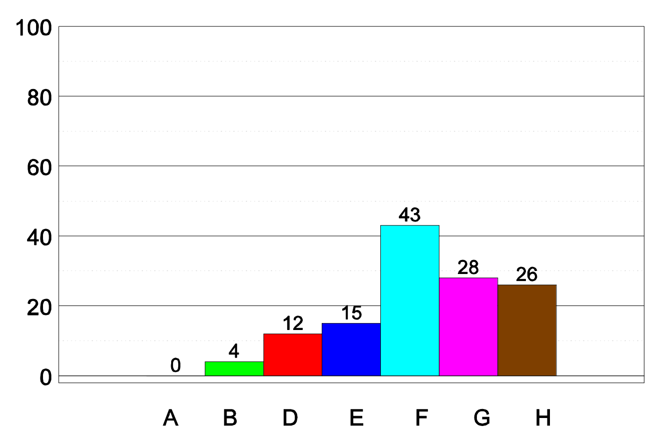

Figure 27. Part II, Question 15: In what percent of all merges did you use the crash avoidance warning information presented by the system?

RESULTS FROM SCORING HUMAN FACTORS CHECKLIST DATA

The data obtained for each system using the Human Factors Checklist was scored according to the method defined in this paper. The categories for which scores were calculated were:

1. Overall Design
2. Visual Warning Display Conspicuity
3. Visual Warning Display Comprehensibility
4. Auditory Warning Discriminability and Comprehensibility
5. System Status Display Conspicuity and Comprehensibility
6. Controls Ergonomics
7. Expert Professional Judgement

It is important to note in viewing the results presented in Table 9 that, in many cases, human factors guidelines were not available for the specification of design characteristics. In these cases, the authors substituted information about desirable interface characteristics based on their extensive experience with CAS. In addition, these results are not discussed as being statistically significant due to the fact that variability in individual system performance was not considered.

For Category 1, Overall Design, the range of scores in Table 9 for the SCAS was from 66.7 to 55.6. These small system to system differences in scores are not considered significant.

For Category 2, Visual Warning Display Conspicuity, Table 9 shows some of the shortcomings of the current version of the Human Factors Checklist. For this category, System F received the best possible rating. However, the visual conspicuity of this crash avoidance warning display actually was observed to be below average. The problem, in this case, was that the visual warning display of System F used very directional LEDs. If a driver's line of sight was on or very near the visual axis of the display's LEDs then the conspicuity of the warning display was excellent. However, if the driver's line of sight was not along the visual axis of the LEDs, then conspicuity was poor. There are no questions in the current version of the checklist that relate to this deficiency. For future use, the Human Factors Checklist will be modified to address this issue.

For Category 3, Visual Warning Display Comprehensibility, Table 9 shows that two systems, A and G, received the best possible scores. Two other systems, B and H, received scores of 72.8. Looking at the differences between the A-G answers and the B-H answers shows that B and H had the lower scores solely because they did not have legends. However, these are quite simple driver interfaces. For example, System B only has one light mounted beneath the side view mirror for its visual warning display. While legends are certainly needed on complex interfaces, perhaps they are not really necessary on simple driver interfaces for this type of system.

For Category 4, Audio Warning Discriminability and Comprehensibility, two systems, D and H, had very low scores. For both of these systems, the meaning of the auditory warnings issued was not readily apparent.

For Category 5, System Status Display Conspicuity and Comprehensibility, the scores ranged from 92.3 to 73.0. This fairly small range of variation was not considered significant.

For Category 6, Control Ergonomics, System B scored poorly due to its violation of population stereotypes and its controls which were difficult to distinguish from one another. The other four SCAS had essentially the same scores.

For Category 7, Expert Professional Judgement, the three commercially available RCAS and SCAS all had good scores ranging from 72.5 to 60.0. While two of the prototype systems also had good scores, four prototype RCAS and SCAS had scores of 40.0 or less. This pattern of variation was expected since the commercially available systems should have more refined, more effective, driver interfaces.

SUMMARY

This paper describes the methodology and evaluation of driver interfaces of a type of electronics-based collision avoidance system that has been recently developed to assist drivers of light vehicles (passenger cars, pickup trucks, vans, and sport utility vehicles). The type of electronics-based collision avoidance system (CAS) is that which *detects* the presence of objects located on the *left and right sides* of the vehicles (referred to as Side-looking Collision Avoidance Systems or SCAS).

A portion of Phase 1 of the research program "Development of Performance Specifications for Systems Which Assist in Avoiding Collisions During Lane Change, Merging, and Backing" was to evaluate the performance of existing systems of this type. As many collision avoidance systems as could be obtained, including several pre-production prototypes, were obtained and tested by TRW and the National Highway Traffic Safety Administration's Vehicle Research and Test Center. The testing focused on measuring the performance of the CAS sensors and evaluating the design of the driver interfaces based on human factors principles. This paper documents the results of the assessment of the design of the driver interfaces for the SCAS tested. A companion report documents the measured performance of the sensors of the side and rear CAS tested [1].

The goals of this assessment of the design of CAS driver interfaces were:

1. To evaluate, based upon the principles of ergonomics, how well the driver interfaces of the collision avoidance systems studied were designed.
2. To provide advice to future designers of collision avoidance system driver interfaces as to ergonomically desirable or undesirable features.
3. To identify CAS driver interface design issues that should be the focus of future research.
4. To improve methods for evaluating CAS driver interface designs.

TABLE 9. System Ratings Based on Scoring of the Human Factors Checklist

	SCAS						
CATEGORY	**A**	**B**	**D**	**E**	**F**	**G**	**H**
1	57.3	64.0	55.6	63.3	56.4	66.7	62.0
2	80.8	80.0	62.8	59.8	100.0	91.0	93.8
3	100.0	72.8	50.0	62.5	54.6	100.0	72.8
4	88.9	88.9	33.3	77.8	N/A	88.9	25.0
5	86.1	73.0	87.0	79.8	81.1	82.4	92.3
6	N/A	46.7	87.2	82.2	N/A	75.6	73.3
7	60.0	67.5	37.5	40.0	68.8	35.0	72.5

For this research, the driver interfaces of seven SCAS were studied. Of these seven systems, two were sold commercially at the time the study was initiated while five were pre-production prototypes. These systems were designated as Systems A, B, and D through H. While the focus of this research was light vehicles (passenger cars, pickup trucks, vans, and sport utility vehicles, all with gross vehicle weight ratings below 44,500 Newtons), several of the systems evaluated were intended primarily for use on heavy trucks. These systems were studied because examining a large number of systems allowed for a better understanding of the needed capabilities of collision avoidance warning systems to be gained.

The principal data collection instrument used to perform a human factors assessment of existing collision avoidance system driver interfaces was a Human Factors Checklist titled "Descriptive Profile, Human Factors Assessment, and Operational Judgements of the Collision Avoidance System Driver/System Interface". The checklist was used both as a research device and as a screening tool. It consisted of a document containing qualitative and quantitative questions and tables. This document served as a tool for the collection of data characterizing collision avoidance system interfaces and their associated visual and auditory information displays and controls.

The checklist contained three sections. Section A was a descriptive profile which addressed the operation of the system hardware and driver displays. Section B consisted of an assessment of the extent to which the visual and auditory displays conformed to established human factors guidelines. Section C consisted of a questionnaire used to assess the operational performance of the driver/system interface by human factors experts after having driven with the systems. Overall, the checklist provided a means by which the effectiveness of the driver/system interface and the merits of systems could be assessed.

In addition to other analyses, the Human Factors Checklist was scored. Scoring was used to reduce the quantity of data generated by the checklist so as to make more apparent the extent to which the driver interfaces incorporated desirable characteristics from a human factors perspective. Driver interface features were assessed based upon human factors guidelines gathered mainly from information presented in the report "Preliminary Human Factors Guidelines for Crash Avoidance Warning Devices" [3] by COMSIS, SAE Recommended Practices, and accepted texts of human factors design principles. Where these sources lacked sufficient information to judge the appropriateness of certain interface characteristics, the authors' judgements based upon extensive experience with using and evaluating collision avoidance systems was substituted.

The Human Factors Checklist used in this assessment was modified for this purpose from its original form developed specifically for use in a study of heavy truck side and rear collision avoidance systems. In modifying this checklist for use in this program, many needed revisions were realized. However, many necessary modifications to the checklist were not apparent until the benefit of retrospect was acquired upon completion of the study. Thus, the limitations of this checklist at this point in time are many. However, the Human Factors Checklist has proved to be a useful resource for assessing CAS driver interfaces. In the future, the checklist should be modified to improve its form and extend its usefulness to encompass new and different CAS types.

Based upon analyses of the completed Human Factors Checklists, the category-by-category scores for each system, and discussions with the two human factors experts, the strengths and weaknesses of each system were identified.

CONCLUSIONS

The first goal of this research was to evaluate, based upon human factors principles, how well the driver interfaces of the collision avoidance systems studied were designed. Overall, while none of systems had an "ideal" driver interface at this point in time, most of the driver interfaces were acceptable from an ergonomic perspective. These findings were similar to those presented in the report "A Study of Commercial Motor Vehicle Electronics-Based Side and Rear Object Detection Systems" [2] which presented results of an evaluation of collision avoidance systems for heavy trucks. Not surprisingly, the commercially available systems tended to have better driver interfaces than did the prototypes.

The second goal of this research was to provide advice to future designers of collision avoidance warning system driver interfaces as to ergonomically desirable or undesirable features. As part of the scoring system, the authors developed a list, for each of six categories, of the characteristics of an ideal system. From these lists, with some minor refinements, the authors have developed their advice to designers.

The authors' advice to designers of collision avoidance system driver interfaces regarding ergonomically desirable or undesirable features varies depending upon the type of system (i.e., rear-looking or side-looking sensors). For SCAS (either left side, right side, or both), Table 10 summarizes this advice.

The advice for driver interface designers that is contained in Table 10 agrees with the interface guidelines contained in "Preliminary Human Factors Guidelines for Crash Avoidance Warning Devices" [3] except for Items 8 and 9. These items recommend that there should be an amber light on the visual warning display that is lit when no object is detected. Therefore, there will always be either a red on amber light lit on the visual warning display. This contradicts conventional human factors wisdom and the interface guidelines contained in "Preliminary

TABLE 10. Desirable Features of a Side-Looking Collision Avoidance System Driver Interface

1. The SCAS driver interface should be very simple and straightforward (from the driver's perspective, not necessarily the manufacturer's!).
2. The SCAS driver interface should provide a crash avoidance warning visual display. The SCAS crash avoidance warning visual display should be located on or near the line of sight to the appropriate side view mirror.
3. The SCAS driver interface should provide a crash avoidance warning auditory display. The SCAS crash avoidance warning auditory display should provide a signal which is audible in a wide range of in-vehicle ambient noise conditions.
4. The SCAS driver interface should provide both auditory and visual crash avoidance warnings in situations when a collision is imminent (i.e., imminent crash avoidance warning).
5. The SCAS driver interface should provide only visual crash avoidance warnings when a collision is possible, but not imminent (i.e.,cautionary crash avoidance warning).
6. The SCAS driver interface should provide auditory warnings only when the appropriate turn signal is activated (or when there is some indication that the driver is about to steer the vehicle to the left or right).
7. The SCAS crash avoidance warning visual display should indicate the presence of an object in the detection zone by illuminating a red light. No other visual displays in the proximity of the primary visual warning display should be illuminated when a visual warning is being issued.
8. The SCAS visual warning display should indicate that no object is present in the detection zone by turning on an amber light and extinguishing the red light.
9. Whenever the system is powered up and functioning properly either the amber light or the red light, but not both, on the dri ver warning visual display will be on.
10. The SCAS driver interface should provide a system status display. The system status should be located in the proximity of the crash avoidance warning visual display to provide the driver with an indication of whether or not the system is operating properly in a common, central location (i.e., near the crash avoidance warning visual display). If the crash avoidance warning visual display incorporates an amber-colored light which is illuminated when no vehicle is present in the detection zone, then this type system status light is not needed.
11. An additional system status visual display may be integrated in the vehicle's instrument panel with other common warning lig hts (e.g., battery voltage). This display should consist of a status light that is normally dark. The status light should illumin ate momentarily when the vehicle is turned on and continuously if a system failure is detected.
12. The SCAS driver interface should provide a means for the driver to adjust the volume of the auditory warning display.
13. The SCAS driver interface should provide a means for the driver to adjust the brightness of the visual displays. Although they did not work well in the interfaces examined in this study, automatic adjustment of visual display brightness may be preferred.
14. Manual controls for volume and brightness should be located on the vehicle's instrument panel.
15. While controls are being manipulated by the driver to adjust the volume or brightness of visual or auditory displays, the SCAS interface should momentarily produce a warning signal to provide the operator with feedback regarding the level of the adjusted parameter.

Human Factors Guidelines for Crash Avoidance Warning Devices" [4] which state that the onset of a signal is more conspicuous than a change in an existing signal. Therefore, warnings will be more conspicuous when there is no signal in the absence of a warning. However, some of the interfaces tested had this feature consisting of a light that was illuminated when no object was detected. Both of the human factors experts who evaluated the interfaces liked this feature and found it helpful for locating the crash avoidance warning display in conditions of low ambient illumination. Therefore, this recommendation is listed in Table 10 even though it contradicts conventional human factors wisdom. This issue should be the topic of additional, future research.

All of the above advice to designers is preliminary in that it was generated by the authors' experiences in examining, and driving with, a substantial number of systems.

The third goal of this research was to identify CAS driver interface design issues that should be the focus of future research. A very reasonable focus of future CAS driver interface design research would be to perform a more in-depth investigation of each of the items of advice for SCAS interface designers contained in Table 10 as well as other relevant issues, such as the problem of designing a collision avoidance warning display which is noticeable but not an unnecessary source of distraction. In-depth investigations of these issues could include experiments to determine such things as driver reaction times using an interface designed in accordance with the authors' advice versus reaction times for interfaces which are based on different designs. However, it is important to realize that it is difficult to evaluate the driver interface of a CAS which has poor sensor performance. Improvements in sensor design as technologies mature should assist this effort.

The fourth goal of this research was to improve methods for evaluating driver interface designs. While the Human Factors Checklist used for this work was much improved over the original heavy truck version, it was apparent by the end of this project that the revised checklist still had some shortcomings. It is recommended that the Human Factors Checklist be revised based upon the findings of this study and allow the checklist to evolve as a tool, as intelligent transportation systems are evolving, for use future research of this type.

ACKNOWLEDGMENTS

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APPENDIX: HUMAN FACTORS CHECKLIST

DESCRIPTIVE PROFILE, HUMAN FACTORS ASSESSMENT, AND OPERATIONAL JUDGEMENTS OF THE COLLISION AVOIDANCE SYSTEM DRIVER/SYSTEM INTERFACE

Date: _____ / _____ / _____

Type of System: _____ **Lane Change / Merge**
(check all that apply) _____ **Backup**

Product Name: ____

Manufacturer
Name and Address: ____
____
____

Test Vehicle: ____
(make, model, year)

Section A Completed by: ____
(Name and position)
Previous experience with this device: ____

Section B Completed by: ____
(Name and position, if different from above)
Previous experience with this device: ____

Section C Completed by: ____
(Name and position, if different from above)
Previous experience with this device: ____

The purpose of this document is to serve as a tool for the collection of data regarding collision avoidance system driver/system interfaces. This document composes both a research device and screening tool by which the merits of systems may be assessed. The information collected includes: 1) descriptions of the operation of system hardware and displays; 2) an assessment of the extent to which the visual and auditory displays conform to established human factors guidelines; and 3) an assessment of operational performance of the driver/system interface. This information may be used to evaluate the effectiveness of the driver/system interface.

The term, "crash avoidance warning," used throughout this document, refers to any information which a system provides to the driver to help prevent an accident. The type of information this warning consists of is dependent on the category of a particular system. Crash avoidance warnings are divided into two categories here: 1) cautionary and 2) imminent. Cautionary crash avoidance warning information is any information provided by a system which warns the driver of a potentially dangerous situation (i.e., obstructing vehicle in an adjacent lane when considering changing lanes, obstructing vehicle to the rear when backing). Imminent crash avoidance warning information refers to any information which a system might provide to warn the driver of an impending collision.

SECTION A: DESCRIPTIVE PROFILE

The purpose of the descriptive profile of the system is to record information regarding the system's operation, sensor configuration, and physical characteristics of the visual and auditory driver displays. These data may be used to evaluate the appropriateness of the display characteristics and the effectiveness of the driver/system interface. This section is to be completed by a human factors expert.

SECTION B: HUMAN FACTORS ASSESSMENT

The purpose of the human factors assessment is to determine the extent to which the design of a particular system's driver/system interface conforms to accepted human factors design principles. These data may be used as stand-alone evaluations or a means for relative comparison among systems. This section is to be completed by one or more human factors experts.

SECTION C: OPERATIONAL JUDGEMENTS OF THE DRIVER/SYSTEM INTERFACE

This section is intended to be subjective assessment of the driver/system interface. Individuals completing this section should include one or more human factors experts per system, if possible. Experts will review the manufacturer's documentation and become familiar with the operation of the system through practice with the device before completing Part I of this section. They will then operate a test vehicle over a fixed route in traffic with an operational system installed in the vehicle. Part II should be filled out after the test drive has been completed. These subjective data form an assessment of the driver/system interface from the user's point of view and provide a means for comparison of this subjective information with objective data collected in other stages of the system evaluation.

SECTION A

DESCRIPTIVE PROFILE OF SYSTEM AND DRIVER/SYSTEM INTERFACE

<u>Instructions for Section A:</u>

- This section is to be completed by a human factors expert.

- Measurements should be taken in a laboratory setting if possible.

- Metric units should be used.

- A detailed 20.32 X 25.4 cm (8 X 10 inch) photograph with ruler in the frame should be taken as part of this data collection effort.

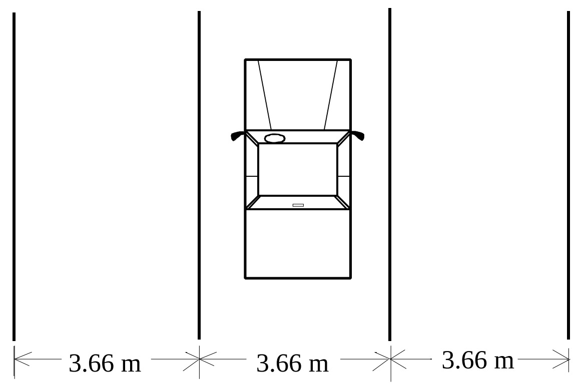
- Suggested references and sources of criteria for use in assessing the appropriateness of the driver/system interface features and the overall effectiveness of this interface include any SAE Recommended Practice. In the event that specific recommendations for some aspect of the interface cannot be found in any SAE recommendation, other sources of human factors design principles, such as 'Preliminary Human Factors Guidelines for Crash Avoidance Warning Devices' (COMSIS, 1993), the 'Human Factors Design Handbook' (Woodson, 1992), the 'Handbook of Human Factors' (Salvendy, 1987), MIL-STD-1472, or other preferred text, may be used. When referencing specific texts, the evaluator should give a full reference (including page number) for the information cited.

Part I General Information

1. Brief system description:

a. What type of sensor technology (e.g., ultrasonic, position radar, etc.) does the system use?

b. How many sensors are used with the system and what areas of coverage are associated with each? Use the given picture to illustrate approximately the detection zone(s) around the vehicle. Dimensions of the detection zones need not be given since this is intended to be an approximate representation.



c. What is the effective (or nominal) range of the sensors as stated in the manufacturer's specifications?

d. Based upon the descriptions contained in the table below, what is the system category? ____________

	Significance of Vehicle Posture	Action Needed
Category 1	Potential for collision exists - vehicle(s) not on a collision course	Caution needed, but no immediate collision avoidance action is necessary
Category 2	Collision is imminent - vehicle(s) on a collision course	Immediate collision avoidance action by the driver is needed
Category 3	Collision is imminent - vehicle(s) on a collision course	Immediate collision avoidance action will be provided by an automatic control system

e. On what type of algorithm are the crash avoidance information, crash avoidance warnings, levels of warning, or vehicle control based (e.g., detection of distance-to-target or time-to-target)? Check one.

Distance-to-target ____
Time-to-target ____
Visual presentation of specified areas ____________________
around the vehicle without use of actual warnings
(e.g., by means of video, optical fiber, etc.)
Other (specify) ____

f. What type of media is used for the manufacturer's documentation? Indicate below with an 'X'.
Attach a copy of the manufacturer's documentation to the back of Section A.

Type of media:	Printed manual	___________
	Audio tape	___________
	Video tape	___________
	Other (specify)	___________
	None	___________

2. In Table I below, list the manufacturer's suggested mounting location for each visual display (and auditory warning unit or control, if separately mounted). Write 'Not Specified' if the manufacturer does not specify mounting locations.

3. In Table I below, list the overall dimensions (width x height x depth) of each display and control unit. **Use millimeters** (round to nearest millimeter).

TABLE I
Mounting Locations and Overall Dimensions

Display, Auditory Message or Control	Overall Dimensions Manufacturer's Recommended Mounting Location	(For reference) (W x H x D)
System status display	________________________	__________ mm
Cautionary crash avoidance warning	________________________	__________ mm
Imminent crash avoidance warning	________________________	__________ mm
Other ______________ (specify)	________________________	__________ mm

Note: Although manufacturers may use a single integrated display, control and warning unit, the organization of Table I provides for multiple units, each separately mounted in different locations in the vehicle. If a single integrated display, control and warning unit is used, please note this in Table I.

4. In Table II below, list the maximum viewing distance to each visual display unit with the system installed in the manufacturer's recommended location(s). Note that the maximum viewing distance for displays mounted in front of the driver is the distance from the seated eye position of the 95th percentile male driver to the center of the visual display. If the manufacturer does not specify a mounting location, assume a mounting location in or on top of the instrument panel within 15 degrees horizontally and vertically of the driver's normal straight-ahead line of sight to the road, and note that this default location is being used.

TABLE II
Maximum Display Viewing Distances

Display	Viewing Distance
System status display	______________ mm
Cautionary crash avoidance warning display	______________ mm
Imminent crash avoidance warning display	______________ mm
Other display ______________________ (specify)	______________ mm

5. In Table III below, list the maximum reach distance* to the control unit with the control unit installed in the manufacturer's recommended location(s). If the manufacturer does not specify a mounting location, assume a mounting location in or on top of the instrument panel within 15 degrees horizontally and vertically of the driver's normal straight-ahead line of sight to the road and use of this default location should be noted. For controls located in front of the driver, the 95th percentile male driver's seated position will determine the maximum reach distance to controls.

* The maximum reach distance is defined to be the straight line distance from the driver's shoulder to the control. The need for reaching around obstructions, such as the steering wheel, should be noted.

TABLE III
Maximum Control Reach Distances

Control Unit	Reach Distance
____________________ (Specify)(e.g., warning volume)	________ mm
____________________ (Specify)	________ mm
____________________ (Specify)	________ mm

6. In Table IV, for each item of information presented by the system, enter information in the appropriate columns.

Notes for Table IV

a. Measure luminances with display removed from vehicle and in a laboratory where illumination levels can be controlled. The displays must be operational for these measurements. For this assessment, assume nighttime and daytime illumination levels of 0.32 lux (0.03 footcandles) and 10,760 lux (1,000 footcandles), respectively. Measure luminances with brightness adjustment control (if present) set at the minimum and maximum settings.

b. Calculate percent contrast using the following formula:

$(L_D - L_B) / L_B \quad x \quad 100$ where L_D = luminance of the displayed information in foot-lamberts
L_B = luminance of the display background in foot-lamberts

c. When measuring the size of alphanumeric characters (and icons) record the height and width of the character, as well as, the stroke width of the character. For alphanumeric characters, the stroke width is the minimum detail that must be resolved by the driver.

d. Assume the maximum viewing distances, as listed in Table II. Compute the visual angle subtended (minutes of arc) using the following formula:

Visual Angle Subtended $= (H / D) \ x \ (57.3 \ ^{degrees}/_{radian}) \ x \ (60 \ ^{minutes}/_{degree})$ where,

H = height of viewed object (or stroke width of character) in millimeters
D = viewing distance in millimeters

7. In Table V below, list the auditory messages that are presented by the system. For each message, enter the information shown at the top of the columns.

Notes for Table V

a. Measure auditory characteristics of messages at the driver's seat with ignition switch off (i.e., engine and all accessories off) and windows up.
b. Measure the loudness of messages (in dB(A)) with the volume adjustment control (if present) in the minimum and maximum loudness settings.
c. Perform an octave band analysis on messages to determine sound intensity level (Note: examine levels by octave band, in units of dB(C); e.g., 500-1000 Hz, 1000-2000 Hz).

8. In Table VI below, for each control, enter the information listed at the top of the columns.

TABLE IV. Descriptive Profile – Visual Displays
(If no display is present for an item listed in the leftmost column, write N/A [not applicable] in the appropriate boxes.)

NAME OF DISPLAYED INFORMATION	TYPE OF INFORMATION DISPLAYED (e.g., indication of object in detection zone, distance to adjacent vehicle)	TRIGGERING EVENT (e.g., power application to system, vehicle in detection zone)	TYPE OF DISPLAY USED (LCD, LED, icon)	TYPE OF COLOR CODING USED	DISPLAY LUMINANCE-DAY (Cd/m^2) (min. & max. brightness setting)	BACKGROUND LUMINANCE-DAY (Cd/m^2)
System on/off						
Cautionary crash avoidance warning						
Imminent crash avoidance warning						
System malfunction						
Other (list)						

TABLE IV. Descriptive Profile – Visual Displays (Continued)
(If no display is present for an item listed in the leftmost column, write N/A [not applicable] in the appropriate boxes.)

NAME OF DISPLAYED INFORMATION	DISPLAY LUMINANCE-NIGHT (min. & max. brightness setting)	BACKGROUND LUMINANCE - NIGHT	CONTRAST (day & night)	DUTY CYCLE (steady burn, flash rate)	SIZE OF DISPLAYED INFORMATION (diameter, smallest character height and width, stroke width)	VISUAL ANGLE SUBTENDED AT MAXIMUM VIEWING DISTANCE (minutes of arc)
System on/off						
Cautionary crash avoidance warning						
Imminent crash avoidance warning						
System malfunction						
Other (list)						

TABLE V. Descriptive Profile – Auditory Warnings

(If no display is present for an item listed in the leftmost column, write N/A [not applicable] in the appropriate boxes.)

TYPE OF AUDITORY SIGNAL	TYPE OF INFORMATION PRESENTED (e.g., indication of object in detection zone, distance to adjacent vehicle)	TRIGGERING EVENT (e.g., power application to system, vehicle in detection zone)	TYPE OF WARNING (steady, warble, intermittent)	PITCH (frequency)	LOUDNESS (record at both min. & max. loudness settings)	DURATION OF AUDIBLE WARNING SIGNAL	DUTY CYCLE (if intermittent, e.g., beeping)	CHANGES AFTER ONSET
System on								
Cautionary crash avoidance warning								
Imminent crash avoidance warning								
System malfunction								
Other (list)								

TABLE VI. Descriptive Profile – Manual Controls

(If no display is present for an item listed in the leftmost column, write N/A [not applicable] in the appropriate boxes.)

CONTROL FUNCTION	CONTROL TYPE (knob, toggle, push button, etc.)	CONTROL SIZE (width X height, diameter, length, etc.)(in mm.)	DOES THE CONTROL OBSTRUCT THE DRIVER'S VIEW OF VISUAL WARNING DISPLAYS	TYPE OF ADJUSTMENT (discrete or continuous)	DESCRIBE TYPE OF CONTROL FEEDBACK (aural, visual, tactile)
System on/off					
Volume adjustment					
Light intensity (dimming) adjustment					
Sensor sensitivity adjustment					
Visual display override					
Audible display override					
Other (list)					

Part II. Checklist of System Features

(All possible features may not be listed here. List other features at the bottom of the page.)
Circle the word which best describes your response.

ND= Not determinable
N/A= Not Applicable

1.	Does the system turn on (i.e., power up) automatically (e.g., when the ignition switch is turned on)?	ND	No	Yes	N/A
2.	Does the system have a power switch which allows the driver to turn the system on or off while driving?	ND	No	Yes	N/A
3.	Is the system on and functioning (i.e., providing warnings) at all times when the vehicle is in motion?	ND	No	Yes	N/A
4.	Is the standby mode of the system's crash avoidance warning features enabled by the ignition switch?	ND	No	Yes	N/A
5.	Does the system use both visual and auditory presentations of crash avoidance warning information?	ND	No	Yes	N/A
6.	Are the visual crash avoidance warning features of the system enabled by the turn signal or sensed lateral motion (or enabled by reverse gear for backup systems)?	ND	No	Yes	N/A
7.	Are the auditory crash avoidance warning features of the system enabled by the turn signal or sensed lateral motion (or enabled by reverse gear for backup systems)?	ND	No	Yes	N/A
8.	Is there a display brightness adjustment for the visual display(s) that can be operated by the driver while driving?	ND	No	Yes	N/A
9.	Is there a volume adjustment for the auditory display(s) that can be operated by the driver while driving?	ND	No	Yes	N/A
10.	Does the system adjust the brightness of the visual display(s) automatically?	ND	No	Yes	N/A
11.	Does the system adjust the volume of the auditory display(s) automatically?	ND	No	Yes	N/A
12.	Is there a temporary manual override control for the visual warning signal(s) for instances when objects known to the driver are encountered in the blind spot?	ND	No	Yes	N/A
13.	Is there a temporary manual override control for the auditory signal(s) for instances when objects known to the driver are encountered in the blind spot?	ND	No	Yes	N/A
14.	Are any visual displays present (i.e., actively presenting information) on the device when there are NO objects sensed in the detection zone?	ND	No	Yes	N/A
15.	Does the system have a "self-test" feature that allows the driver to check for proper operation of visual and auditory displays and logic circuits while driving?	ND	No	Yes	N/A
16.	Does the system have an automatic indicator of sensor failure?	ND	No	Yes	N/A
17.	Does the system have an automatic indicator of visual display failure?	ND	No	Yes	N/A
18.	Does the system have an automatic indicator of auditory display failure?	ND	No	Yes	N/A
19.	Is there a sensor sensitivity adjustment control present that can be adjusted by the driver while the vehicle is in motion?	ND	No	Yes	N/A

SECTION B:

HUMAN FACTORS ASSESSMENT OF THE DRIVER/SYSTEM INTERFACE

(In the material to follow, the term, "appropriate", means compliance with accepted SAE Recommended Practices and/or human factors design principles)

Instructions for Section B:
- This section is to be completed by one or more human factors experts.
- The individual completing this section should be familiar with the referenced SAE Recommended Practices and human factors guidelines before beginning this section.
- Measurements made in Section A may be used in determining the appropriateness of design characteristics.
- Suggested references and sources of criteria for use in assessing the appropriateness of the driver/system interface features and the overall effectiveness of this interface include any SAE Recommended Practice. In the event that specific recommendations for some aspect of the interface cannot be found in any SAE recommendation, other sources of human factors design principles, such as 'Preliminary Human Factors Guidelines for Crash Avoidance Warning Devices' (COMSIS, 1993), the 'Human Factors Design Handbook' (Woodson, 1992), the 'Handbook of Human Factors' (Salvendy, 1987), MIL-STD-1472, or other preferred text, may be used. When referencing specific texts, the evaluator should give a full reference (including page number) for the information cited.

Part I. Crash Avoidance Warning Visual Displays

Circle the number or word which best describes your response.

ND=Not determinable
N/A=Not applicable

A. General

1.	Is displayed crash avoidance warning information labeled?	ND	No	Yes	N/A
2.	Are the information coding methods used (e.g., size, shape, brightness, color) for crash avoidance warning appropriate for the type of information presented?	ND	No	Yes	N/A
3.	Do the information coding techniques used for crash avoidance warnings conform to population stereotypes (e.g., brighter or larger displayed information for traffic closer to the driver)?	ND	No	Yes	N/A
4.	Is crash avoidance warning information presented using appropriate redundant visual codes (e.g., simultaneous brightness and size increases as traffic gets closer)?	ND	No	Yes	N/A
5.	Does the organization of crash avoidance warning information facilitate quick acquisition of information while driving?	ND	No	Yes	N/A

B. <u>Cautionary</u> Crash Avoidance Warnings - Visual

6.	Are any cautionary crash avoidance warning visual displays for this system located within 15 degrees horizontally and vertically of the driver's line of sight to the right side mirrors? (for right side systems)	ND	No	Yes	N/A
7.	Are any cautionary crash avoidance warning visual displays for this system located within 15 degrees horizontally and vertically of the driver's line of sight to the left side mirrors? (for left side systems)	ND	No	Yes	N/A
8.	Are any cautionary crash avoidance warning visual displays for this system located within 15 degrees horizontally and vertically of the driver's straight-ahead line of sight to the road?	ND	No	Yes	N/A
9.	Is the presence of any right side cautionary crash avoidance warning visual signal noticeable when the driver looks at the right side view mirrors?	ND	No	Yes	N/A

10. Is the presence of any left side cautionary crash avoidance warning visual signal noticeable when the driver looks at the left side view mirrors? ND No Yes N/A

11. Is the presence of cautionary crash avoidance warning visual signal(s) noticeable when the driver looks at the inside rear view mirror? ND No Yes N/A

12. Is the presence of any right side cautionary crash avoidance warning visual signal noticeable when the driver looks straight ahead? ND No Yes N/A

13. Is the presence of any left side cautionary crash avoidance warning visual signal noticeable when the driver looks straight ahead? ND No Yes N/A

14. Is the presence of any right side cautionary crash avoidance warning visual signal noticeable when the driver looks midway between the right side A and B pillars? ND No Yes N/A

15. Is the presence of any left side cautionary crash avoidance warning visual signal noticeable when the driver looks midway between the left side A and B pillars? ND No Yes N/A

16. Is the driver's line of sight to all cautionary crash avoidance warning visual displays unobstructed (e.g., by other controls, displays or vehicle components)? ND No Yes N/A

17. Can the driver discriminate the cautionary crash avoidance warning from all other proximally displayed information (e.g., system status information)? ND No Yes N/A

18. Are all cautionary crash avoidance warning displays discernible in daylight? ND No Yes N/A

19. Are all cautionary crash avoidance warning displays discernible in darkness? ND No Yes N/A

20. Are all cautionary crash avoidance warning displays discernible in light from specular glare sources (e.g., overhead street lights, sun)?

	Very Ineffectively major changes needed		Somewhat Effectively some changes needed		Very Effectively few changes needed	
ND	1	2	3	4	5	N/A

21. How effectively have SAE Recommended Practices and human factors design principles been applied to the design of the cautionary crash avoidance warning visual displays?

C. <u>Imminent</u> Crash Avoidance Warnings - Visual ND No Yes N/A

22. Are any imminent crash avoidance warning visual displays for this system located within 15 degrees horizontally and vertically of the driver's line of sight to the right side mirrors? (for right side systems) ND No Yes N/A

23. Are any imminent crash avoidance warning visual displays for this system located within 15 degrees horizontally and vertically of the driver's line of sight to the left side mirrors? (for left side mirrors) ND No Yes N/A

24. Are any imminent crash avoidance warning visual displays for this system located within 15 degrees horizontally and vertically of the driver's straight-ahead line of sight to the road? ND No Yes N/A

25. Is the presence of any right side imminent crash avoidance warning visual signal noticeable when the driver looks at the right side view mirrors? ND No Yes N/A

26. Is the presence of any left side imminent crash avoidance warning visual signal noticeable when the driver looks at the left side view mirrors? ND No Yes N/A

27. Is the presence of imminent crash avoidance warning visual signal(s) noticeable when the driver looks at the inside rear view mirror?

ND No Yes N/A

28. Is the presence of any right side imminent crash avoidance warning visual signal noticeable when the driver looks straight ahead? ND No Yes N/A

29. Is the presence of any left side imminent crash avoidance warning visual signal noticeable when the driver looks straight ahead? ND No Yes N/A

30. Is the presence of any right side imminent crash avoidance warning visual signal noticeable when the driver looks midway between the right side A and B pillars? ND No Yes N/A

31. Is the presence of any left side imminent crash avoidance warning visual signal noticeable when the driver looks midway between the left side A and B pillars? ND No Yes N/A

32. Is the driver's line of sight to the imminent crash avoidance warning visual displays unobstructed (e.g., by other controls, displays or vehicle components)? ND No Yes N/A

33. Can the driver discriminate the imminent crash avoidance warning from all other proximally displayed information (e.g., system status information)? ND No Yes N/A

34. Are all imminent crash avoidance warning displays discernible in daylight? ND No Yes N/A

35. Are all imminent crash avoidance warning displays discernible in darkness? ND No Yes N/A

36. Are all imminent crash avoidance warning displays discernible in light from specular glare sources (e.g., overhead street lights, sun)? ND No Yes N/A

Very Ineffectively major changes needed — **Somewhat Effectively some changes needed** — **Very Effectively few changes needed**

37. How effectively have SAE Recommended Practices and human factors design principles been applied to the design of the imminent crash avoidance warning visual displays? ND 1 2 3 4 5 N/A

Very Ineffectively major changes needed — **Somewhat Effectively some changes needed** — **Very Effectively few changes needed**

Summary for Crash Avoidance Warning Visual Displays

38. How effectively have the crash avoidance warning visual display(s) been designed to help drivers make right lane changes without collision? ND 1 2 3 4 5 N/A

39. How effectively have the crash avoidance warning visual display(s) been designed to help drivers make left lane changes without collision? ND 1 2 3 4 5 N/A

40. How effectively have the crash avoidance warning visual display(s) been designed to help drivers make right merges without collision? ND 1 2 3 4 5 N/A

41. How effectively have the crash avoidance warning visual display(s) been designed to help drivers make left merges without collision? ND 1 2 3 4 5 N/A

42. How effectively have the crash avoidance warning visual display(s) been designed to assist drivers in backing without collision? ND 1 2 3 4 5 N/A

Part II. Crash Avoidance Warnings - Auditory

Circle the number or word which best describes your response.

ND=Not determinable
N/A=Not applicable

A. General

1. Is the lowest volume setting at least 60 dBA?	ND No Yes N/A
2. Is the highest volume setting not more than 90 dBA?	ND No Yes N/A
3. Is the frequency (i.e., tone) of auditory warnings between 500 and 3000 Hz?	ND No Yes N/A
4. Are complex tones (vs. pure tones) used for auditory warnings?	ND No Yes N/A
5. Are the meanings of the auditory warnings easy for the driver to understand?	ND No Yes N/A
6. How many of levels of auditory crash avoidance warnings are used?	________________

B. Cautionary Crash Avoidance Warnings - Auditory

7. Are the coding methods (e.g., "beep rate", tonal changes or loudness changes) appropriate for the type of cautionary crash avoidance warning presented?	ND No Yes N/A
8. Do coding methods used for cautionary crash avoidance warning conform to population stereotypes (e.g., higher pitched or faster beeping) for traffic closer to the vehicle?	ND No Yes N/A
9. Can the driver discriminate among the levels of coding used for the cautionary crash avoidance warnings (e.g., not more than four discrete levels of loudness)?	ND No Yes N/A
10. Can the driver discriminate the cautionary crash avoidance warning from other in-vehicle auditory warnings?	ND No Yes N/A

11. How effectively have SAE Recommended Practices and human factors design principles been applied to the design of cautionary crash avoidance warning auditory displays?

	Very Ineffectively major changes needed		Somewhat Effectively some changes needed		Very Effectively few changes needed	
ND	1	2	3	4	5	N/A

C. Imminent Crash Avoidance Warnings - Auditory

12. Are the coding methods (e.g., "beep rate", tonal or loudness changes) appropriate for the type of imminent crash avoidance warning presented?	ND No Yes N/A
13. Do coding methods used for imminent crash avoidance warnings conform to population stereotypes (e.g., higher pitched or faster beeping) for traffic closer to the vehicle?	ND No Yes N/A
14. Can the driver discriminate the crash avoidance warning from other in-vehicle auditory warnings?	ND No Yes N/A

15. How effectively have SAE Recommended Practices and human factors design principles been applied to the design of imminent crash avoidance warning auditory displays?

	Very Ineffectively major changes needed		Somewhat Effectively some changes needed		Very Effectively few changes needed	
ND	1	2	3	4	5	N/A

Summary for Crash Avoidance Warning Auditory Displays

	ND	1	2	3	4	5	N/A
		Very Ineffectively major changes needed		Somewhat Effectively some changes needed		Very Effectively few changes needed	
16. How effectively have the auditory crash avoidance warnings been designed to help drivers make right lane changes without collision?	ND	1	2	3	4	5	N/A
17. How effectively have the auditory crash avoidance warning display(s) been designed to help drivers make left lane changes without collision?	ND	1	2	3	4	5	N/A
18. How effectively have the auditory crash avoidance warning display(s) been designed to help drivers make right merges without collision?	ND	1	2	3	4	5	N/A
19. How effectively have the auditory crash avoidance warning display(s) been designed to help drivers make left merges without collision?	ND	1	2	3	4	5	N/A
20. How effectively have the auditory crash avoidance warning display(s) been designed to assist drivers in backing without collision?	ND	1	2	3	4	5	N/A

Part III. Auxiliary Information: System Status Displays

ND = Not Determinable
N/A = Not Applicable

A. <u>System Status - Visual:</u> (e.g., power, display intensity, system failure status, sensor sensitivity)

1. Can the driver discriminate from the display whether the system is on or off (i.e., powered or unpowered)?	ND	No	Yes	N/A
2. Does the display present the setting status of driver adjustable parameters (e.g., brightness, volume controls, alarm intensity)?	ND	No	Yes	N/A
3. Is displayed system status information labeled?	ND	No	Yes	N/A
4. Are the status displays discernible in daylight?	ND	No	Yes	N/A
5. Are the status displays discernible in darkness?	ND	No	Yes	N/A
6. Are the status displays discernible in light from specular glare sources (e.g., street lights, sun)?	ND	No	Yes	N/A
7. Are the information coding methods used for system status information (e.g., green for okay) appropriate for the type of information presented (when variable levels exist)?	ND	No	Yes	N/A
8. Do the information coding techniques used conform to population stereotypes (e.g., red for a malfunction indicator)?	ND	No	Yes	N/A
9. Are appropriate levels of coding used to present system status information to facilitate ease of discrimination among levels?	ND	No	Yes	N/A
10. Does the organization of system status information facilitate quick acquisition of information presented while driving?	ND	No	Yes	N/A
11. Can system status information be sufficiently discriminated from any other visual displays in the device?	ND	No	Yes	N/A

B. System Status - Auditory (If relevant.)

12. Is an auditory signal used to present system status information?	ND No Yes N/A
13. Are the coding methods (e.g., "beep rate", tonal changes or loudness changes) appropriate for the type of status information presented?	ND No Yes N/A
14. Do coding methods for status auditory warnings conform to population stereotypes?	ND No Yes N/A
15. Are multiple levels of coding auditory status information used?	ND No Yes N/A
16. Can the driver discriminate among the levels of coding used (e.g., not more than four discrete levels of loudness)?	ND No Yes N/A
17. Can the driver discriminate system status information from other in vehicle auditory warnings?	ND No Yes N/A

Part IV. Auxiliary Information: Manual Controls
Circle the number or word which best describes your response.

ND = Not Determinable
N/A = Not Applicable

1. Does the driver have an unobstructed view of the controls from the forward driving position?	ND No Yes N/A
2. Are all controls labeled?	ND No Yes N/A
3. Are controls coded (size, shape, location, activation movement) for discrimination in blind operation?	ND No Yes N/A
4. Are controls separated to prevent accidental activation of controls adjacent to the one intended by the driver?	ND No Yes N/A
5. Does movement of all controls conform to population stereotypes (e.g., upward, right or clockwise movement to produce an increase in the value of a parameter)?	ND No Yes N/A
6. Does the use of each control provide visual feedback?	ND No Yes N/A
7. Does the use of each control provide tactile feedback? (e.g., detents, position, displacement)	ND No Yes N/A
8. Does the use of each control provide auditory feedback (e.g., "clicks" or a volume change)?	ND No Yes N/A
9. Are control legends illuminated for viewing under nighttime driving conditions?	ND No Yes N/A
10. Are control legends discernible in bright sunlight?	ND No Yes N/A
11. Are controls located such that the driver does not have to assume an awkward posture to operate the controls?	ND No Yes N/A
12. Is the appropriate control used for the type of function to be controlled? (e.g., avoiding toggle switches for volume control)	ND No Yes N/A
13. Do the controls provide their setting status on visual or tactile inspection?	ND No Yes N/A

Part V. Auxiliary Information: Legends

Circle the number or word which best describes your response.

ND= Not Determinable
N/A= Not Applicable

1. Are legends present on the driver/system interface?	ND	No	Yes	N/A
2. Does the driver have an unobstructed view of each legend?	ND	No	Yes	N/A
3. Are the legends discernible in daylight?	ND	No	Yes	N/A
4. Are the legends discernible in darkness?	ND	No	Yes	N/A
5. Are all legends discernible in light from specular glare sources (e.g., street lights, sun)?	ND	No	Yes	N/A
6. Are legends located in acceptable positions with respect to their associated control or display?	ND	No	Yes	N/A
7. Are functional legends easily discriminated from advertising legends?	ND	No	Yes	N/A

Part VI. Auxiliary Information: Documentation

For purposes of this section of the evaluation, the term documentation refers to material provided by the device manufacturer that describes system installation, calibration, operation, use and maintenance. This material could be distributed on a variety of media, including printed manuals, video tapes, audio tapes or CD ROM.

Type of documentation (circle all that apply): Brochure Audio Tape Manual Video Tape Other _____________

General (Circle the number or word which best describes your response; ND= Not Determinable, N/A= Not Applicable)

1. Does the documentation identify the device as supplemental to normal driver visual sampling of mirrors, etc.?	ND	No	Yes	N/A
2. Does the documentation identify conditions under which system performance is degraded?	ND	No	Yes	N/A
3. Does the documentation describe how to operate the system?	ND	No	Yes	N/A
4. Does the documentation describe mounting locations for display(s), audible warning devices and controls?	ND	No	Yes	N/A
5. Does the documentation describe installation procedures?	ND	No	Yes	N/A
6. Does the documentation describe calibration procedures?	ND	No	Yes	N/A
7. Does the documentation describe maintenance procedures?	ND	No	Yes	N/A
8. Does the documentation give "trouble shooting" tips for common problems?	ND	No	Yes	N/A

Part VII. Overall Summary of Driver Interface

		Very Ineffectively major changes needed		**Somewhat Effectively some changes needed**		**Very Effectively few changes needed**	
1. Considering the control, display, warning, legend and discrimination issues presented above, how effectively has this system been designed from a human factors perspective?	ND	1	2	3	4	5	N/A

SECTION C

OPERATIONAL JUDGEMENTS OF THE COLLISION AVOIDANCE SYSTEM DRIVER/SYSTEM INTERFACE

Name:______________________ Test Vehicle:______________________

System:______________________ Date:_________________ Day / Night ?

Amount of driving experience with this system: ____

This section is to be completed by one or more human factors experts. It is desirable to have multiple human factors experts complete this section to allow for comparison and consolidation of responses. The test route will contain approximately 45 minutes of each of the following road types: arterial, highway, and rural highway. This route will be driven in the morning, in daylight conditions and not during rush hour. The same (or an equivalent) route should be driven in darkness.

<u>Instructions for Section C:</u>

- Before beginning this section, the human factors expert should be provided with the manufacturer's instructions for use of the system and become familiar with the operation of the system through practice with the device.

- **Part I** should be completed first (before the human factors expert drives with the system). Part I is to be filled out in the test vehicle with the engine running.

- After completing Part I, the human factors expert will operate the test vehicle with an operational system installed in the vehicle over a fixed route in traffic and traversing the Columbus, Ohio area and containing approximately equal amounts of time spent on arterial, highway, and rural highway.

- **Part II** is to be completed after the human factors expert has completed driving with the system over the test route. This section should be completed while the subject is still seated in the test vehicle. This part of section C may be repeated after driving the route under nighttime conditions to collect data on interface effectiveness in a darkened environment.

- **Part III** consists of a qualitative summary in which the human factors expert records information regarding their experience with the system after having just driven with it. This section should be completed while the human factors expert is still in the test vehicle.

- Suggested references and sources of criteria for use in assessing the appropriateness of the driver/system interface features and the overall effectiveness of this interface include any SAE Recommended Practice. In the event that specific recommendations for some aspect of the interface cannot be found in any SAE recommendation, other sources of human factors design principles, such as 'Preliminary Human Factors Guidelines for Crash Avoidance Warning Devices' (COMSIS, 1993), the 'Human Factors Design Handbook' (Woodson, 1992), the 'Handbook of Human Factors' (Salvendy, 1987), MIL-STD-1472, or other preferred text, may be used. When referencing specific texts, the evaluator should give a full reference (including page number) for the information cited.

<u>Note:</u> For the purposes of this document, please note the following definitions:

"Crash Avoidance Warning" (CAW) - refers to any information which a system provides to the driver to help prevent an accident. The type of information this warning consists of is dependent on the category of a particular system. CAWs are divided into two categories: 1) cautionary and 2) imminent. CAW information is any information provided by a system which warns the driver of a potentially dangerous situation (i.e., obstructing vehicle in an adjacent lane when considering changing lanes, obstructing vehicle to the rear when backing). Imminent CAW information refers to any information which a system might provide to warn the driver of an impending collision.

Distract - (*v.t.*) to draw away or divert, as the mind or attention.

Annoy - (*v.t.*) to disturb (a person) in a way that displeases, troubles, or slightly irritates.

Part I. Static Evaluation

Circle the number or word which best describes your response.

ND= Not Determinable
N/A= Not Applicable

1. How clearly does the documentation tell you . .

		Not At All Clear				Very Clear	
a. The purpose of the system	ND	1	2	3	4	5	N/A
b. How to turn on/off the system	ND	1	2	3	4	5	N/A
c. How to operate and use the system	ND	1	2	3	4	5	N/A

2. Was there any information regarding the use of the system which you needed, but was not included in the documentation? ____________________

3. How discernible is the crash avoidance warning display?

		Not At All Readable				Very Readable	
	ND	1	2	3	4	5	N/A

4. How effective is the 'system test' feature for understanding the status of:

		Very Ineffective				Very Effective	
a. The crash avoidance warning visual displays?	ND	1	2	3	4	5	N/A
b. The auditory crash avoidance warnings?	ND	1	2	3	4	5	N/A

5. How easy to understand are the meanings of

		Very Difficult				Very Easy	
a. The system status information visual displays?	ND	1	2	3	4	5	N/A
b. The system status auditory displays?	ND	1	2	3	4	5	N/A
c. The cautionary crash avoidance warning visual displays?	ND	1	2	3	4	5	N/A
d. The imminent crash avoidance warning visual displays?	ND	1	2	3	4	5	N/A
e. The cautionary crash avoidance warning auditory displays?	ND	1	2	3	4	5	N/A
f. The imminent crash avoidance warning auditory displays?	ND	1	2	3	4	5	N/A

Part II. Dynamic Evaluation (conducted <u>after</u> road test with system): **** DRIVING SUMMARY ****

The human factors expert shall record the following items about the test run:

System Tested: ______________________ Test Vehicle: _________________ Start Time: _______ End Time: _______

Circle as appropriate:

Traffic Conditions: Light Moderate Heavy

Ambient Light: Day (Specify: gloomy, moderate sunlight, bright sunlight) Night

Driving conditions: Dry Road Wet Road Rain Snow

Mirror Configuration on Test Vehicle (describe): ______________________________________

Was the mirror system adequate? ______________________________

1. While driving, how discernible were the following visual displays:		Not At All Discernible				Very Discernible	
a. System status display(s)?	ND	1	2	3	4	5	N/A
b. Crash avoidance warning display(s)?	ND	1	2	3	4	5	N/A
2. While driving, how well could system status information be discriminated from any other nearby displays in the device?		very difficult to discriminate				very easy to to discriminate	
	ND	1	2	3	4	5	N/A
3. While driving, how well could crash avoidance warning displays be discriminated from any other nearby displays in the device?		very difficult to discriminate				very easy to to discriminate	
	ND	1	2	3	4	5	N/A
4. While driving, how distracting were the following visual displays:		very distracting				Not at all distracting	
a. System status display(s)?	ND	1	2	3	4	5	N/A
b. Cautionary crash avoidance warning display(s)?	ND	1	2	3	4	5	N/A
c. Imminent crash avoidance warning display(s)?	ND	1	2	3	4	5	N/A
5. While driving, how distracting were the following auditory displays:		very distracting				Not at all distracting	
a. System status display(s)?	ND	1	2	3	4	5	N/A
b. Cautionary crash avoidance warning display(s)?	ND	1	2	3	4	5	N/A
c. Imminent crash avoidance warning display(s)?	ND	1	2	3	4	5	N/A
6. While driving, how annoying were the following auditory displays:		very annoying				not at all annoying	
a. System status display(s)?	ND	1	2	3	4	5	N/A
b. Cautionary crash avoidance warning display(s)?	ND	1	2	3	4	5	N/A
c. Imminent crash avoidance warning display(s)?	ND	1	2	3	4	5	N/A

7. How would you describe the loudness of the auditory warnings compared to what you would expect for a warning system like this?

ND Too Low OK Too High N/A

8. How would you describe the

pitch (tone) of the auditory warnings compared to what you would expect for a warning system like this?	ND Too Low OK Too High N/A
	Not At All Effective ... Very Effective
9. How effective was the visual crash avoidance warning presentation in helping you to make...	
a. right lane changes (for right side systems)?	ND 1 2 3 4 5 N/A
b. left lane changes (for left side systems)?	ND 1 2 3 4 5 N/A
	Not At All Effective ... Very Effective
10. How effective was the visual crash avoidance warning presentation in helping you to merge...	
a. to the right (for right side systems)?	ND 1 2 3 4 5 N/A
b. to the left (for left side systems)?	ND 1 2 3 4 5 N/A
	Not At All Effective ... Very Effective
11. How effective was the visual crash avoidance warning presentation in helping you perform backing maneuvers (for backing systems)?	ND 1 2 3 4 5 N/A
	Not At All Effective ... Very Effective
12. How effective was the auditory crash avoidance warning presentation in helping you perform backing maneuvers (for backing systems)?	ND 1 2 3 4 5 N/A
	Not At All Effective ... Very Effective
13. How effective was the auditory crash avoidance warning in helping you to make...	
a. right lane changes (for right side systems)?	ND 1 2 3 4 5 N/A
b. left lane changes (for left side systems)?	ND 1 2 3 4 5 N/A
	Not At All Effective ... Very Effective
14. How effective was the auditory crash avoidance warning presentation in helping you to merge...	
a. to the right (for right systems)?	ND 1 2 3 4 5 N/A
b. to the left (for left side systems)?	ND 1 2 3 4 5 N/A
15. Did you use the (side) crash avoidance warning information presented by the system to make a decision about a lane change?	ND No Yes N/A
About what percent of all lane changes?	________ N/A
16. Did you use the crash avoidance warning information presented by the system to make a decision about merging (for side systems)?	ND No Yes N/A
About what percent of all merges?	________ N/A
17. Did you use the crash avoidance warning information presented by the system to make a decision about a backing maneuver (for backing systems)?	ND No Yes N/A
About what percent of all backing maneuvers?	________ N/A
18. Before you made a lane change or merging maneuver, did the crash avoidance warning information presented by the system cause you to use your mirrors more, less or about the same as you normally do?	
a. Left side mirror (for left side systems)	ND Less Same More N/A
b. Right side mirror (for right side systems)	ND Less Same More N/A
c. Rear view mirror (for rear systems)	ND Less Same More N/A

19. When changing lanes or merging, did the crash avoidance warning information presented by the system cause you to look out the side windows more, less or about the same as you normally do?

a. Left side (for left side systems)	ND	Less	Same	More	N/A
b. Right side (for right side systems)	ND	Less	Same	More	N/A

20. Before you made a backing maneuver, did the rear crash avoidance warning information presented by the system cause you to use your mirrors more, less or about the same as you normally do?

a. Left side mirror	ND	Less	Same	More	N/A
b. Right side mirror	ND	Less	Same	More	N/A
c. Rear view mirror	ND	Less	Same	More	N/A

21. When backing, did the rear crash avoidance warning information presented by the system cause you to look out the windows more, less or about the same as you normally do?

a. Left side window	ND	Less	Same	More	N/A
b. Right side window	ND	Less	Same	More	N/A

Part III. Qualitative Driving Summary

1. How much time and effort did it take to get used to the system and become familiar with the operation of its interface?

2. What problems, if any, did you have in using the system interface? [List]

3. Of the problems identified above, which ones were the biggest problems for you and why?

4. Was the crash avoidance information presented by the system sufficiently noticeable when driving?

5. Was the crash avoidance information presented by the system easy to understand and useful?

6. Was the format in which the crash avoidance information was presented appropriate?

7. Did you experience any problems with glare (during the day due to sun, or at night) or other factor which hindered your perception of information presented by the system?

8. To what extent did you make (or almost make) an error of judgement when using the system? Explain.

9. To what extent was the presence of the system (driver/system interface) a distraction while driving (What aspects of the driver/system interface were distracting)? Why?

10. Did you find any part of the driver/system interface to be annoying while driving? What was annoying and why?

11. Did you visually sample the display when not making a lane change (for lane change/merge systems)?

12. Overall, how effectively has this system's interface been designed to help drivers make lane changes? Merges? Backing maneuvers?

13. If you could talk to the engineer who designed this system, what changes would you recommend to improve the **driver/system interface**?

14. If you could talk to the engineer who designed this system, what changes would you recommend to improve the **overall operation of the system**?

15. Would you be willing to buy this system (as tested) for your vehicle (car, truck)? Why or why not?